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NAS REPORT ON TECHNOLOGICAL FEASIBILITY OF 1975-76 MOTOR VEHICLE EMISSION STANDARDS

FEASIBILITY OF MEETING THE 1975-1976 EXHAUST EMISSION STANDARDS IN ACTUAL USE

NATIONAL ACADEMY OF SCIENCES

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

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The document also contains a Minority Report on "Analytical Investigation of Feasibility of Meeting the 1975-76 Exhaust Emission Standards in Actual Use.

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FEASIBILITY OF MEETING THE 1975-76 EXHAUST EMISSION STANDARDS IN ACTUAL USE

Prepared by the Panel on

Testing, Inspection, and Maintenance

for the

COMMITTEE ON MOTOR VEHICLE EMISSIONS

of the

NATIONAL ACADEMY OF SCIENCES

June 1973

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NOTICE

The Committee on Motor Vehicle Emissions has evaluated the technological feasibility of meeting the light-duty motor vehicle emissions standards as prescribed by the Clean Air Amendments of 1970. This study was performed under the sponsorship of the National Academy of Sciences and with the express approval of the Governing Board of the National Research Council.

The Committee obtained much of its information from eight panels of consultants, each panel dealing with a particular subject area of importance in the Committee deliberations. Panel members were selected by the Committee on the basis of recognized competence in specific areas.

The panel reports are reports of the panels to the Committee. Before publication, each panel report was reviewed by appointed members of the Committee. The views represented by the panels are one of the sources of information provided to the Committee and were used as a partial basis for the Committee judgments.

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PREFACE

In legislating the Clean Air Amendments of 1970, the Congress asked the Environmental Protection Agency to contract with the National Academy of Sciences to conduct a comprehensive study and investigation of the technological feasibility of meeting the motor vehicle emissions standards prescribed in accordance with the law. In responding to this request, pursuant to a contract with the Environmental Protection Agency, the Academy established a committee on Motor Vehicle Emissions and charged it with the conduct of this study. The Committee published the results of its work in a report to the Environmental Protection Agency dated February 12, 1973.

As means of providing itself with authoritative information and expertise in the various critical aspects of the problem it undertook to study, the Committee appointed specialist panels to undertake investigations and report their findings. The following report, Feasibility of Meeting the 1975-76 Exhaust Emission Standards in Actual Use, presents the findings of one of those panels.

Taken together, the special panel reports constitute a very substantial accumulation of data and analysis brought together by many specialists in many investigations in a very fast-moving area of technological development. In its published report, the Committee on Motor Vehicle Emissions has, of course, brought together that part of all this information and analysis required to fulfill its stated obligation to the Environmental Protection Agency. The separate reports of the specialist panels are published for the public record and to complete the documentary record.

The reader should note that most of the data referred to in this report were obtained prior to September 1972. Also, the investigation was completed before any relaxation of the 1975-1976 exhaust emission standards.

One of the panel members, Mrs. Marian Chew, felt that certain aspects of the determination of technological feasibility of meeting emission standards in use were not covered adequately by the main panel report. Thus, she has prepared a spearate report, Analytical Investigation of Feasibility of Meeting the 1975-76 Exhaust Emission Standards in Actual Use. This report is bound herein with the main panel report, and a covering letter by Mrs. Chew explains her main reasons for submitting the report.

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Abstract

The Panel on Testing, Inspection, and Maintenance of Vehicles took as its charge investigating the feasibility of methods of ensuring that 1975-1976 cars meet the emission standards in actual use for 50,000 miles. Fulfilling this responsibility required consideration of all of the testing steps connected with the life of a car, from development of an engineering prototype to the maintenance of a single vehicle by a mechanic. It was also necessary to consider the relationships among the tests used at various points in the sequence of steps, since the appropriate action at many points is determined by actions that precede and follow the one in question. The requirements of the Clean Air Act of 1970 and how these requirements are interpreted into administrative action will have a large effect on the sequence of testing steps that must be used. This is particularly noticeable with regard to the choice between a control philosophy designed to reduce emissions by controlling the average emissions from all cars and a philosophy of controlling the emissions from every car.

Factors affecting feasibility are the durability of proposed control systems, deterioration of components and adjustments, contamination of catalysts by fuels and lubes, adequacy of the service industry, adequacy of replacement parts, the level of emissions from cars with inoperative control systems, and the availability of state programs for ensuring proper maintenance. The proposed control systems, particularly the catalyst, are significantly less durable than present hardware. The required factor of about 2 for the deterioration of emission levels in 50,000 miles has not been achieved. The probability of catalyst contamination by fuels and lubes is high, particularly for the first two or three years. Pollutant levels in exhaust, untreated because of inoperative control systems, will be 10 to 20 times higher than levels from properly functioning systems. The service industry will not be properly trained and equipped and the state programs ensuring the mandatory maintenance will not be operating by 1975. Consideration of all these factors led the Panel to conclude that

1. The proposed 1975-1976 vehicles will not meet the standards in actual use.

2. Mandatory maintenance is necessary in order to achieve maximum benefit from the new systems, but it is not sufficient to ensure meeting the standards.

3. There is no feasible method for ensuring that the proposed 1975-1976 cars meet the standards in actual use.

4. Maintenance based on an improved service industry is the foundation of any system for achieving maximum benefit from the proposed 1975-1976 control systems or from alternative control systems.

1 INTRODUCTION

The purpose of the National Academy of Sciences study was, in the words of Section 202(c)(1) of the Clean Air Act of 1970,[*] "to conduct a comprehensive study and investigation of the technological feasibility of meeting the emission standards." Consequently, Panel 2 (Testing, Inspection and Maintenance) accepted as its charge "to investigate the feasibility of methods of ensuring that the 1975-1976 cars will meet, in actual use, the emission standards required by the Act." In the absence of an official definition, the Panel developed the following: "Meeting the standards in actual use, by a class[+] of vehicles, is assumed to mean that the average emissions of that class will remain at or below the certification standards for 50,000 miles." This definition is a practical interpretation of the law and is based on the fact that average emissions control air pollution. If every car is required to meet the standards, the outlook for feasibility will be far more pessimistic than that reflected in this report.

It is impossible to prove whether there is or is not a feasible method of ensuring that the 1975-1976 cars meet the standards in actual use, if "prove" is used in the sense normally connected with scientific investigations. Data on behavior in actual use do not exist for either the 1975 or 1976 systems. Prototype vehicles have been tested, but not one car has been delivered to a member of the public to drive in his normal way and to be maintained by the service industry available to the average owner.

There is, however, evidence bearing on the feasibility of ensuring that the cars meet the standards in actual use, and this

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[*] Hereafter referred to as the Act.

[+] Class is used to mean similar vehicles produced by the same manufacturer and equipped with the same engine and control system. Although "class" is not defined in the Act, it is used in this sense, e.g., Section 202(a)(1) and Section 207(c)(1).

report will present such evidence and the Panel's analysis of the evidence. The Panel believes that the evidence on feasibility when viewed as a total package is quite convincing even though individual pieces of evidence may not be. Available evidence on the feasibility of methods of ensuring that cars meet the standards in actual use applies almost equally to proposed 1975 and 1976 systems, with the exception that the 1976 systems will probably be more complicated and, consequently, more difficult to maintain.

An investigation of "feasibility of methods of ensuring that cars meet the standards in actual use" is, by necessity, much broader than a simple comparison of the relative merits of various inspection/maintenance regimes or various tests to determine the state of adjustment of a vehicle. Testing, inspection, and maintenance is control; control of every step in the long sequence of events starting with the development of an engineering prototype vehicle and ending with the maintenance (adjustment or repair) of a car by an individual mechanic. Appropriate action at a particular point is often dependent on the actions taken at earlier steps in the sequence and even, in the case of certain control philosophies, on actions that will be taken later in the sequence. Consequently, any method of ensuring meeting the standards must be discussed on the basis of consideration of the entire testing sequence.

The Panel charge and definition refer to meeting the standards in the legal sense defined by the Act, and feasibility will be evaluated on this basis. There are, however, other aspects of the basic problem of reducing vehicle pollution that may become important as the situation develops, and some discussion of these is included for completeness.

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2 ELEMENTS OF THE TOTAL TESTING AND MAINTENANCE SEQUENCE

IMPACT OF THE ACT ON THE SEQUENCE

The Act and the EPA regulations promulgated on the basis of it either prescribe or allow the Administrator to prescribe the following testing steps in the life of an automobile:

1. Exhaust emission standards and the test procedure by which exhaust emissions are to be measured.
2. Certification of prototype models. This is required before the issuance of a Certificate of Conformity permitting the manufacture and sale of a class of vehicles.
3. Testing after manufacture to ensure that production vehicles are meeting appropriate standards. Failure at this point can result in withdrawal of the Certificate of Conformity.
4. Testing to determine if a class of vehicles in actual use is conforming to the official standards. Failure to conform would result in the manufacturer being required to remedy the nonconformity at his expense.
5. Testing to determine whether each vehicle in actual use is complying with the official standards. Nonconformity of an individual car, if such nonconformity results in the owner having to bear any penalty or sanction under either Federal or State law, would result in the manufacturer having to remedy the nonconformity at the manufacturer's expense if the car has been properly maintained. The authority to specify this test implies the authority to prescribe the inspection method to be used by the states.

In addition to the above list, which is prescribed by the Act, there are other necessary or likely steps:

2a. Testing during engineering development of prototype models. Many tests will be used but the principal one will be the official CVS-1975 test on which the certification depends.

3a. Testing during manufacture to ensure that production vehicles conform to the prototype design and, therefore, will meet the appropriate standards.

6. Surveillance testing of vehicles in use for determining average emissions under real rather than artificial conditions and for some other purposes.

7. Testing as part of a program to minimize emissions from individual cars.

All of these nine testing steps are related; both the degree of interrelationships and the complexity of the total sequence depend on the control philosophy. The last four steps may be left to the discretion of manufacturers or states, but steps 6 and 7 could be the same as 4 and 5 under the terms of the Act.

GENERAL FLOW OF THE TESTING SEQUENCE AND INTERRELATIONSHIPS AMONG STEPS

Relationship to the Primary Objective

The wording of Section 202(a)(1) makes clear that the primary objective of the Act was to reduce the contribution of vehicle emissions to air pollution by 90 percent. It is not known exactly how this percentage reduction was selected, but a logical basis would have been an analysis of the reduction in pollutants needed to attain the ambient air quality standards and of what fraction of this reduction it was necessary to achieve by controlling automotive emissions. The essential steps in such an analysis are shown in Figure 1.

Neither the details nor the correctness of this analysis is relevant to this summary. However, all subsequent steps pertaining to testing and maintenance are based on two facts inherent in such an

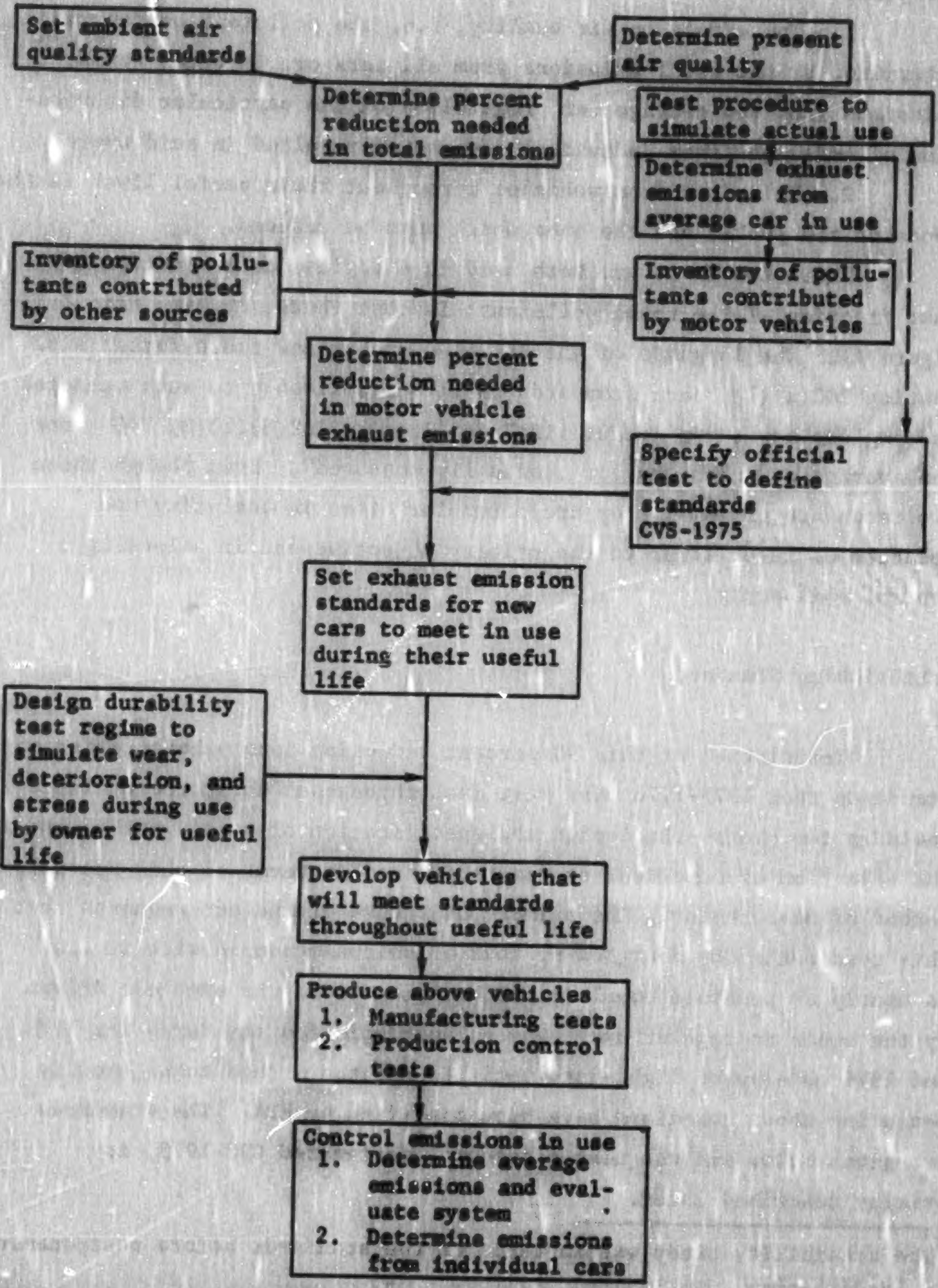
Set ambient air quality standards
Determine present air quality
Determine percent reduction needed in total emissions
Test procedure to simulate actual use
Determine exhaust emissions from average car in use
Inventory of pollutants contributed by other sources
Inventory of pollutants contributed by motor vehicles
Determine percent reduction needed in motor vehicle exhaust emissions
Specify official test to define standards CVS-1975
Set exhaust emission standards for new cars to meet in use during their useful life
Design durability test regime to simulate wear, deterioration, and stress during use by owner for useful life
Devolop vehicles that will meet standards throughout useful life
Produce above vehicles
1. Manufacturing tests
2. Production control tests
Control emissions in use
1. Determine average emissions and evaluate system
2. Determine emissions from individual cars

FIGURE 1 Interrelationships among steps in a testing sequence.

analysis. These are

1. The effect on air quality, i.e. the pollutant burden, is determined by the total emissions from all cars or, in other terms, the emissions from the average car, regardless of the particular distribution of emissions from individual cars which resulted in said average.

2. Emissions from vehicles throughout their useful lives in the hands of the public are the ones which must be reduced.

These two facts are both used in a logical determination of what fraction of the total pollutants is contributed by cars (see Figure 1). The language of the Act also emphasizes these facts; e.g. Section 202(a)(1) "such standards shall be applicable to such vehicles and engines for their useful life" and Section 202(b)(1)(B) "90% from the average of emissions . . . actually measured". Even though these two facts are truisms, they are often forgotten in analyzing the relation of later steps to the primary objective and in selecting a control philosophy.

Establishing Standards

Translation of this 90 percent reduction into exhaust emission standards that 1975-1976 cars must meet throughout their useful lives includes two steps: the design and specification of a test method and the selection of numerical standards defined in terms of this specific method of measurement. The primary objective of the Act requires that this test method be designed so that emissions measured with it are as nearly as possible equal to the emissions from the same car driven by the owner in regular use. The exhaust emission standards for 1975 and 1976 model-year light-duty vehicles and the method to be used in measuring these emissions have been specified by EPA. The standards* are given below and the test procedure, designated CVS-1975, is briefly described later.

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*The feasibility study was in terms of the standards before postponement or relaxation.

	HC (g/mi)	CO (g/mi)	NO_x (g/mi)
1975	0.41	3.4	3.1
1976	0.41	3.4	0.40

To attain the required reduction of emissions from cars in use, tests for three different purposes are needed: to control engineering development, to control production, and to control emissions from cars in the hands of the public.

Control of Engineering Development

Engineering prototype vehicles must be developed, and since the standards apply throughout the useful life, procedures for simulating the wear, deterioration, and stresses that would occur during the life of the vehicle in an owner's hands are required. Again the emphasis is on equivalence to real-life conditions. Tests during development are at the discretion of the manufacturer except that a class of vehicles is not certified for production and sale until prototypes of the class have met the standards throughout testing by the EPA Certification Procedure.

Control of Production

There are two purposes here: controlling actual manufacture and testing the finished product. In both cases the emphasis is on tests to aid in producing cars that will perform like the prototypes.

Tests at various points in the manufacturing process to ensure that the production vehicles will conform to the design of the prototypes are left to the discretion of the manufacturer. Consequently, great variety can be expected, but these tests will probably be of four types: performance tests on components, functional tests at various points in the assembly, tests to determine adherence to dimensional specifications, and, possibly, a simple pass-fail emissions test at the end to detect major errors in assembly. The performance tests on components may be useful as diagnostic tests on cars in use and the functional tests should be useful both as diagnostic and inspection tests. The success of the tests used to control manufacture will certainly affect the implementation of the legally-required subsequent testing, but the results of these tests are not data that will be referred to in any subsequent tests. A list of typical manufacturing tests is shown in Appendix A.

Production of new motor vehicles under a Certificate of Conformity calls for some control procedures to ensure that production vehicles are substantially equivalent to the prototypes that passed certification testing. Applicable sections of the Act [Sec. 206 (b), (c), (d), and (e)] authorize the Administrator to establish methods and procedures for making tests for this purpose.

Establishment of such methods and procedures will require decisions on a number of factors relating certification testing to testing of production vehicles. The formal Certification Procedure cannot practicably be performed on any sizeable sample of production vehicles because of the time involved. The test selected will depend on the control philosophy. Are emissions from production vehicles to be controlled on the basis of average emissions or emissions from each car? Both the letter from the EPA administrator to Chrysler dated Feb. 8, 1972, and the Decision of the Administrator re Applications for Suspension of 1975 Motor Vehicle Exhaust Emission Standards dated May 12, 1972, indicate that EPA will allow averaging of the emission test results from production vehicles in order to determine compliance. However, neither of these documents makes it clear whether an audit of a statistically significant sample or testing of every vehicle is intended.

Even though other test methods could be used for this quality audit, the logical test is the CVS-1975. Audit testing by the CVS-1975 test would be adequate to ensure that the average emissions from production vehicles met appropriate production line standards that are designed to correspond to the certification standards. Such production standards should take into account the "green engine" factor,[*] a presumed useful-life deterioration factor, and possibly a production-model tolerance factor reflecting the normal expected difference between mass-production vehicles and the pre-production prototype vehicles used for certification testing. Correlation of emissions data measured during certification, audit testing, and surveillance testing of cars in use--all by the CVS-1975 test--should rapidly make possible accurate prediction of behavior in use from the certification and audit results. Use of tests other than the official test at these three points in the sequence would essentially eliminate this possibility.

If the law is finally interpreted to require that every car must meet some appropriate standards at the time of manufacture, or if the average emission is determined by testing each car, a short, hot-start test will have to be used. Use of such a test would add one more complication to the selection of a production line standard designed to correspond to the certification standards, namely, the fact that hot-start and cold-start tests do not pass and fail the same vehicles because cold-start emissions predominate in 1975-1976 control systems. This and other difficulties connected with an every-car approach are discussed in more detail later.

Both methods of testing finished vehicles can be used to improve the control of manufacture through failure-mode analysis.

Statistical evaluation of emissions data from production vehicles is the logical choice because of the variability of emissions testing superimposed on the variability of vehicle manufacture. The mean of a sample of adequate size is a better control measure than the percentage of cars that must meet the standards. Regardless of whether the percentage that must meet specified standards is 90, 99, or 100 percent, the average emissions from the production vehicles will be higher for a narrow distribution in emissions than for a wide one. This means that closer quality control (a desirable result) will

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[*] Difference in emission levels between zero and 4,000 miles.

result in an increase in average emissions (an undesirable result) unless the standards are continually revised. This does not occur if the compliance standards apply to the average emissions.

Control of Emissions in Use

Surveillance testing of the proper sample by the CVS-1975 test will determine if the average car in use is meeting the official standards. If the surveillance data are obtained on the basis of vehicle class, vehicle mileage, and before and after proper adjustment and maintenance, the results can be used for several purposes:

1. To determine emissions from the average car.
2. To evaluate deterioration in use.
3. To evaluate the prescribed maintenance procedures.
4. To develop information on failure modes that can be used as feedback to improve either manufacturing control or system design.
5. To establish, possibly, the need to recall a class of vehicles.

Such surveillance testing, however, would be needed in any event to assess the real behavior of control systems in public use as compared with the artificial conditions of certification testing.

If emissions data are determined for every car, the results can be used for the purposes listed above and can also be used

1. To ensure that each vehicle and its emission control system are performing properly at the time of inspection, and

2. To enforce the individual-vehicle warranty provision of the Act.

There are several testing and inspection methods that can be used in attempting to accomplish item 1, and their relative merits depend on several factors, including the engineering design of cars, which

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are discussed later. If a single test is to be used for items 1 and 2, it should be the same one used to check every car at the end of the assembly line (see Control of Production). Any test to be applied to every car must be applicable when the engine is warm (a hot-start test) since the vehicles will be driven to the test site and the time required for cooling down would make any cold-engine test completely unfeasible.

3 TESTING AND MAINTENANCE METHODS

CVS-1975 TEST

The 1975 and 1976 EPA emissions standards are defined in terms of an emissions test known as the CVS-1975 test (1). Basic elements of the test are a dynamometer driving cycle, a sample collection method, and analytical apparatus and techniques. The vehicle is tested on a chassis dynamometer after a temperature-conditioning period of between 60 and 86°F for at least 12 hours. The test cycle takes 41 minutes and the temperature during testing is specified to be between 68 and 86°F. The key is turned on and exhaust gas sampling begins immediately whether the engine starts or not and continues until the engine stops, even if it "diesels" after key-off. The entire exhaust gas stream is mixed with purified ambient air and passed through a heat exchanger to make a constant volume flow of variably diluted exhaust gas. Samples drawn at a constant rate from this diluted stream are collected and analyzed for hydrocarbons, carbon monoxide, oxides of nitrogen, and carbon dioxide by specified methods. The constant volume sampling (CVS) system automatically weights the vehicle's varying exhaust gas flow rate, and emissions are calculated in mass units of grams per mile by multiplying the sample concentrations by the total CVS flow and appropriate constants.

While the number of tests required for certification of an engine family is only between 20 and 50, other applications of the test, such as developmental testing, possible assembly-line-quality audit tests (200,000 or 300,000 annually), and surveillance of in-use vehicles make the test time (cost) an important consideration.

The total test time could probably be shortened, but drastically shortening the soak period would affect emission results. A 6-hour soak period and a cycle with a running time of about 23 minutes have been shown to produce results (2) having high correlation with the

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full CVS-1975 test. However, since the test is the primary design criterion for the performance of emissions-control systems, it should be sufficiently complex to avoid "cycle-beating" tactics.

As stated previously, the primary objective of the Act requires that the CVS-1975 test measure the same emissions, as nearly as possible as would occur if the car were driven by an owner in regular usage. There are three questions:

1. Does the CVS-1975 driving cycle represent an average urban trip?
2. Is the ratio between cold-start and hot-start emissions in the CVS-1975 test the same as the ratio of cold to hot starts in normal urban driving?
3. Are the experimental conditions (temperature, humidity, barometric pressure, etc.) representative of the conditions under which the cars will be driven?

The answer to question 1 is, "As well as it needs to." The emissions from the probable 1975 and 1976 control systems appear not to be sensitive to the driving cycle used in the test (3). This is an expected result of the fact that the emissions of HC and CO during the first 1 or 2 minutes after cold start predominate over the rest of the emissions and that the emission of NO_x would only be changed by a significant change in the amount of high-speed driving. Data submitted by Chrysler (2) show no large differences in emissions from such vehicles tested on a five-city average driving cycle and the CVS-1975 cycle. This five-city average was developed on an APRAC project (CAPE-10) (4) to determine driving habits in five major cities. An AMA project (5) based on this study developed a computer model for generating cycles based on combinations of driving types. Table 1 shows some comparative data from this study; included are the LA-4, CVS (modified LA-4), CAPE-10 LA, and the five-city composite.

TABLE 1 Comparison of Driving Cycles

	Average Speed (mph)	Time Composition in Percent			
		Idle	Cruise	Accel.	Decel.
LA-4	20.9	13.6	27.3	31.7	27.5
CVS-EPA	19.7	18.2	30.2	27.7	23.9
CAPE-10 LA	29.3	10.1	34.3	29.8	25.8
CAPE-10 composite	26.0	13.1	31.5	29.2	26.3

The answer to question 2 about the validity of the relative weighting of cold- and hot-start emissions in a test cycle is particularly critical to the evaluation of 1975-1976 control technology. The transition from engine-modification to exhaust-gas-treatment systems changed the relative contributions of the emissions during the cold and hot portions of the test to the point where the first few minutes of operation contribute the major fraction of the composite mass emissions of HC and CO from probable 1975-type systems (6). Figures 2 and 3 both show individual-mode emissions in the Federal cycle from a cold start. It is clear from Figure 3 that the majority of the HC and CO emissions occur in the first mode and that as soon as the catalytic converter warms up the emissions are very low. The emissions of NO_x do not behave in this manner since NO_x emissions are not being controlled by a thermal device. However, use of a catalytic converter to control NO_x in 1976 systems will cause a similar warm-up effect; the magnitude of the effect will depend on whether or not the catalyst is the only NO_x control device. Thus, even though 1970-1971 baseline emissions are measured by the same method specified for the 1975-1976 standards, the choice of cold-start weighting has a large influence on the technological demand for 1975-1976.

The CVS-1975 cycle is based (7,8) on a vehicle speed trace of a Los Angeles traffic route known as LA-4 (9). The route was developed by California agencies to simulate weekday morning peak driving conditions in a 12-mile diameter circle centered on the downtown area.

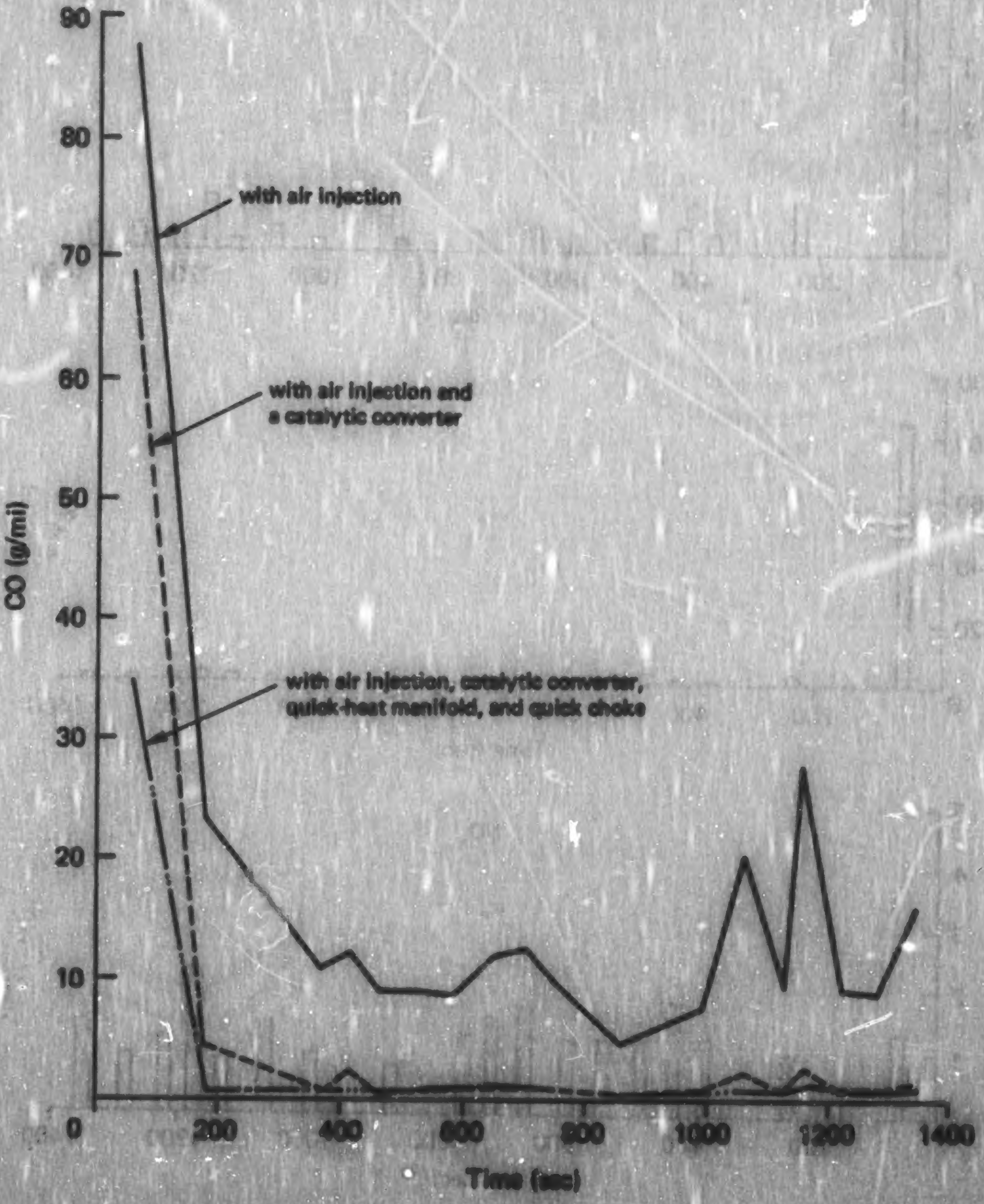

FIGURE 2 Comparison of CO emissions from cars with engine-modification and exhaust-gas-treatment systems.

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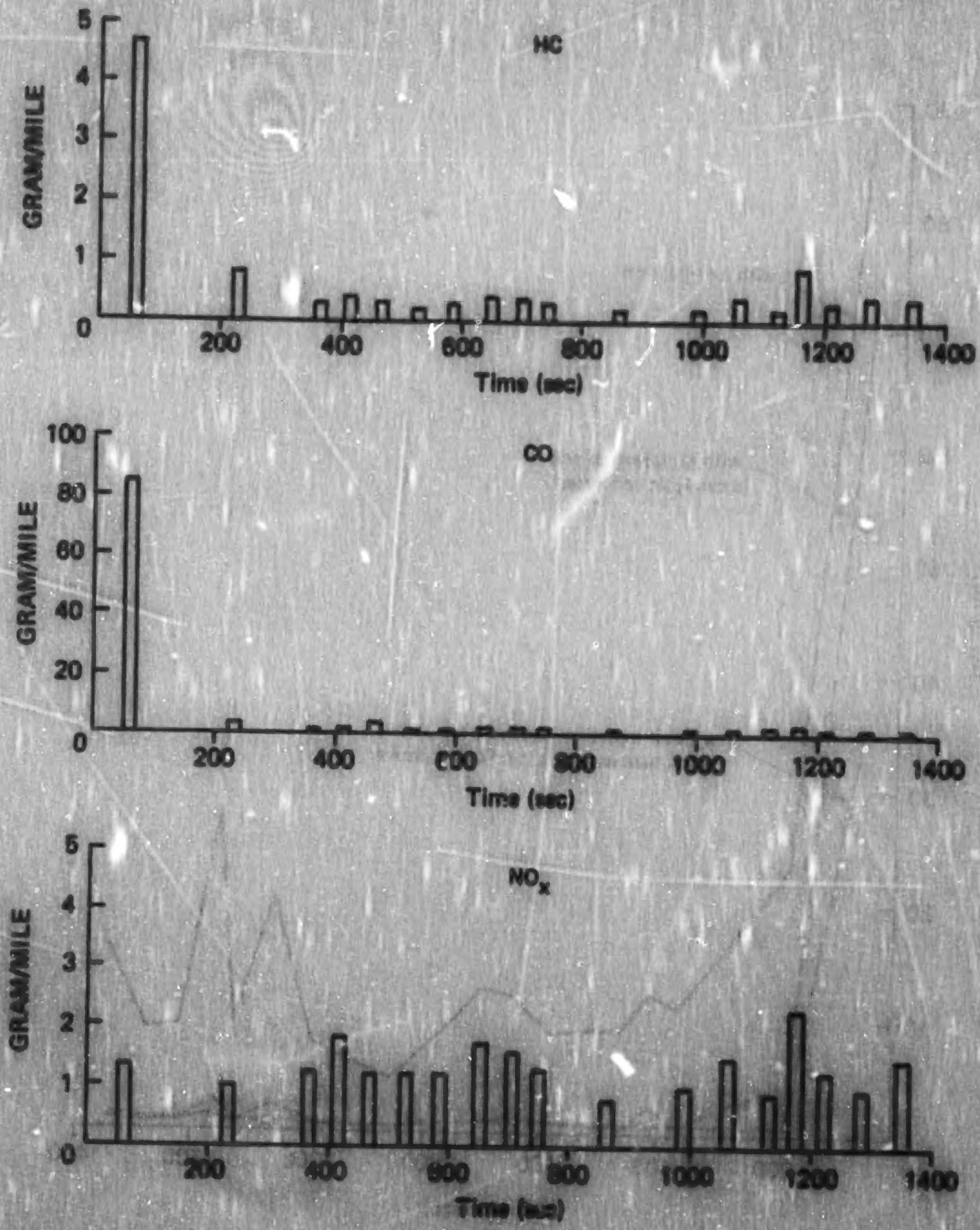


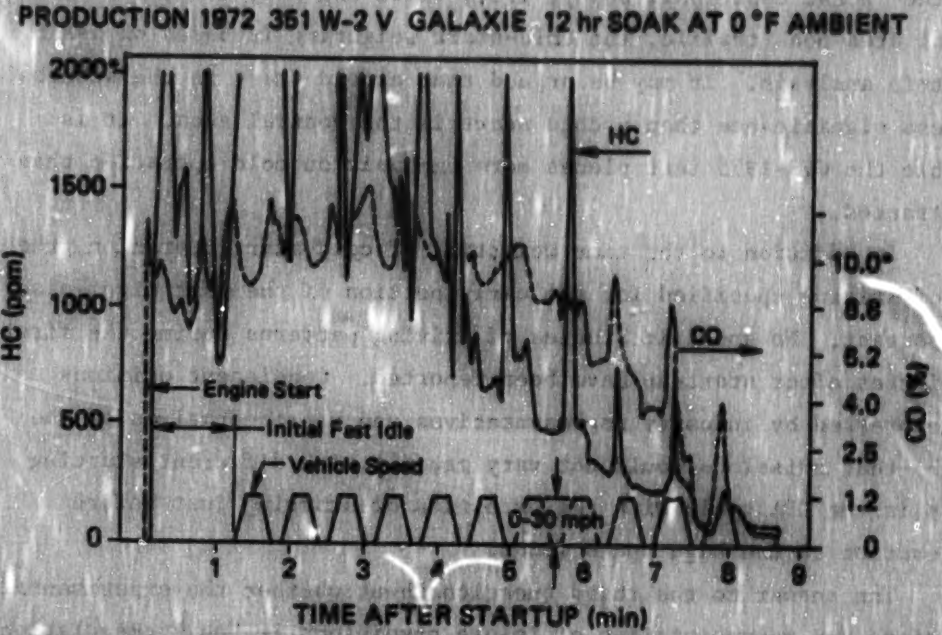
FIGURE 3 Cold-start effect on emission test.

It represents a "worst case" philosophy in that the peak concentrations of photochemical smog precursors are believed to occur during the Los Angeles morning commute period. Part of the LA-4 cycle was adopted as the EPA cycle for tests through 1974 models and this test was further modified by decreasing the cold-start weighting and including a hot re-start to give the CVS-1975 test.

The cold-start weighting selected by EPA is an apparent departure from the "worst case" philosophy; i.e., while the test cycle represents central area peak traffic, the cold-start weighting is based on basin wide trip analysis. It may be argued that a cold start in the suburbs has less significance than a cold start in the central area. It is possible the CVS-1975 test places more emphasis on cold operation than is warranted.

In addition to the time weighting of cold-start operation, the type of driving specified for the early portion of the test might also be important. No specific studies of driving patterns during the first few minutes after start-up have been reported. Consistent opinions were expressed by industry representatives and representatives of the EPA (3) that emissions would not vary greatly with different starting points in the EPA cycle with the exception of starting just before acceleration to the high speed modes.

The answer to the third question about whether the experimental conditions are representative of in-use conditions is "no." Regulations specify cold soak between 60 and 86°F and testing between 68 and 86°F, and an EPA representative (3) expressed concern over the fact that this temperature range is not really representative of conditions in large parts of the nation during either winter or summer and suggested adding tests at other temperatures. Tests at other temperatures and barometric pressures would certainly yield different emission values. Starting a car at temperatures often found during winter in large sections of the nation, e.g., 0 to 32°F, would cause large increases in emissions. The result of one such test is shown in Figure 4, furnished to the Panel by Ford. The Department of Air Resources, City of New York (10), has also studied the effect of cold starts at low temperatures and some of their



*HC/CO PEAKS EXCEEDED RANGE OF INSTRUMENT CALIBRATION

FIGURE 4 Effect of low ambient temperature on cold-start emissions.

results are shown in Table 2 for starts at 20°F. Hydrocarbons show an increase of 63 percent and CO 56 percent over starts at the normal test temperatures (68 to 86°F). It should be noted that these data were not obtained on systems that include catalytic converters. However, the predominance of cold-start emissions under the 1975-1976 conditions amplifies the effect of starts at low temperatures. This is shown by the data in Table 3, which gives the actual average increases in g/mi and the average percentage increases in HC and CO emissions for seven cars when tested at 20, 40, and 70°F (11). The data are given as differences between 40 and 70°F and between 20 and 70°F. All of these vehicles were equipped with catalytic converters and the average differences are made smaller by the inclusion of one car operating on LPG and another starting on LPG. It is not clear how much effect on air pollution these extra emissions have, but in the strict sense the CVS-1975 test is not representative of all actual driving conditions.

The CVS-1975 test variability is particularly relevant to the understanding and application of approval test data, production test data, and implementation of warranty provisions. The next section discusses the repeatability of emission tests, so it suffices now to note that the overall import of the variability problem is such that any single test of a 1975-1976 vehicle is likely to deviate from the true value by more than 50 percent due to chance testing factors and vehicle variability. It is apparent that no important consequences should be attached to a single test.

REPEATABILITY OF EXHAUST EMISSION MEASUREMENTS

Measurements of exhaust emissions have poor repeatability. Two-thirds of the variation in test results is caused by the vehicle: its driving history prior to testing, its average cold-soak temperature, and its own individual handling characteristics during the test cycle. This variability is not peculiar to 1975-1976 vehicles but it is aggravated by the much more stringent standards. The remaining one-

TABLE 2 Cold-Weather Tests, 1972 Federal Test Procedure[a]

Test No.	Date	Soak Temp. (°F)	HC g/mi	CO g/mi	NO g/mi
137	2/7/72	12	1.26	14.5	4.55
145	2/11/72	21	1.18	14.0	4.62
156	2/24/72	27	1.02	14.4	4.40
	$\overline{X}$	20	1.15	14.3	4.52
	σ		0.10	0.22	0.09
	Variability		8.7	1.5	2.0
Corresponding "normal" Fed. '72					
		Mean	0.72	8.06	4.71
% Change due to cold			+62.6	+56.4	-4.20

[a] All tests were run on a 1972 Hornet.

TABLE 3 Cold Weather Tests

	HC		CO	
	%	g/mi	%	g/mi
40°F compared with 70°F	36	0.15	69	5.90
20°F compared with 70°F	113	0.47	122	11.09

third of the test variability is caused by using the analytical instruments at a poor signal-to-noise ratio in order to determine the low concentrations of pollutants required to meet the 1975-1976 standards.

The Department of Air Resources, City of New York (10), states that the coefficient of variation for the 1972 Federal CVS test is about 15 to 20 percent (see Table 4). New York City obtained these results just after the EPA had reviewed the New York testing techniques and found them to be in order. Furthermore, New York states that these results are consistent with results from other laboratories.

Coefficients of variation and total data range in percent of the mean are given in Table 5 as determined by GM for six cars (12) with the 1972 Federal CVS test. The coefficients of variation are a little smaller than those determined by New York City, but are in the same range. When the CVS-1975 test was applied to current vehicles a coefficient of variation from 10 to 20 percent was obtained (13).

The data in Table 5 were all from the same test cell for each car. Another problem is variation from test cell to test cell or from laboratory to laboratory. Table 6 shows GM data (12) on variations between test cells; the mean differences are small but the range of differences approaches 100 percent. EPA and the manufacturers have a continuing program of interlaboratory comparisons and some typical results are shown in Figures 5 and 6. These are tests on 1973 cars by the 1973 Federal test and they again show significant differences between the two laboratories.

Some of the reasons for this lack of repeatability are the bench operator, driver, car, test dynamometer, attachment to exhaust, constant volume sampler (CVS), sample itself, and analyzing instruments. External but important variables are ambient conditions and the recent driving history of the car (more of a factor in real life than in manufacturers' tests).

When a similar or the same test (CVS) is applied to prototype 1975-1976 systems the probable percentage error increases by a factor of 2 to 3, even though the absolute error remains constant, since the emission levels have decreased by about a factor of 10 from 1972.

TABLE 4a

Comparison of Test Procedures--Type of Start

	1972 Federal Cold Start	NYC Comprehensive Hot Start	NYC Quick Hot Start
Total time (min)	22.83	3.33	1.25
Total distance (mi)	7.5	0.72	0.28
Average speed (MPH)	19.7	13.0	13.4
Top speed (MPH)	56.7	40	30

TABLE 4b

Comparison of Test Procedures--Repeatability (Hornet Data)

	Coefficients of variation		
CO	15.0	34.6	4.14[b]
HC	22.2	21.9	1.19[b]
NO_x	22.3	26.8	12.91[b]

---

[a] $\sigma/\bar{x}$ X 100.

[b] Scott Research recommends that two quick cycles be run concurrently. (This datum is based on three concurrent tests.)

TABLE 5

Typical Variations at 1972 Levels, 1972 Cold-Start EPA Test

	σ/M^a			% Range[b]		
	HC	CO	NO_x	HC	CO	NO_x
Car #1 (5 tests)	4.4	5.0	21.8	13.6	14.4	33.9
Car #2 (4 tests)	14.0	8.6	9.4	38.5	22.4	23.6
Car #3 (4 tests)	7.9	24.7	8.3	16.9	55.9	20.6
Car #4 (4 tests)	8.8	6.8	20.1	24.4	17.0	44.0
Car #5 (5 tests)	9.9	24.6	12.0	27.0	60.6	27.6
Car #6 (4 tests)	6.5	4.9	28.2	16.1	12.7	71.9
Average	8.6	12.4	15.0	22.8	30.5	36.9

[a] σ/M = Standard deviation as a percent of the mean.

[b] % range = Total data range as a percent of the mean.

TABLE 6

Typical Cell-to-Cell Variations, 1972 Emission Level Vehicles

24 Paired Observations--Cold Starts, 1972 EPA Test

	HC	CO	NO_x
σ/M[a]	24.1	20.0	12.5
% range[b]	91.2	94.9	42.9
Mean differences	5.2	2.1	16.9

[a] σ/M = Standard deviation of paired differences as a percent of the mean of the paired differences.

[b] % range = Total data range of paired differences as a percent of the mean of the paired differences.

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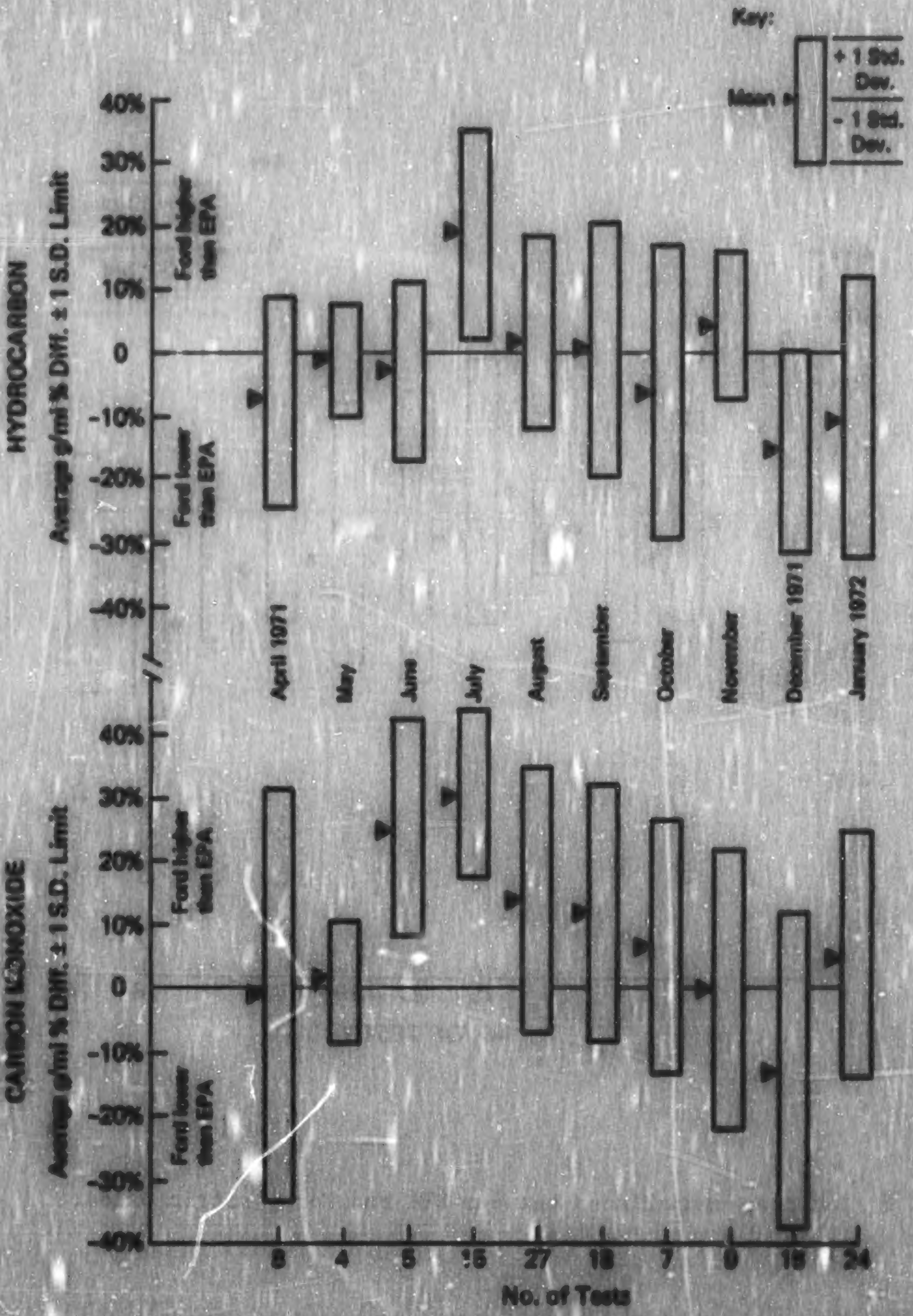

FIGURE 5 Interlap comparisons between EPA and Ford, carbon monoxide and hydrocarbons.

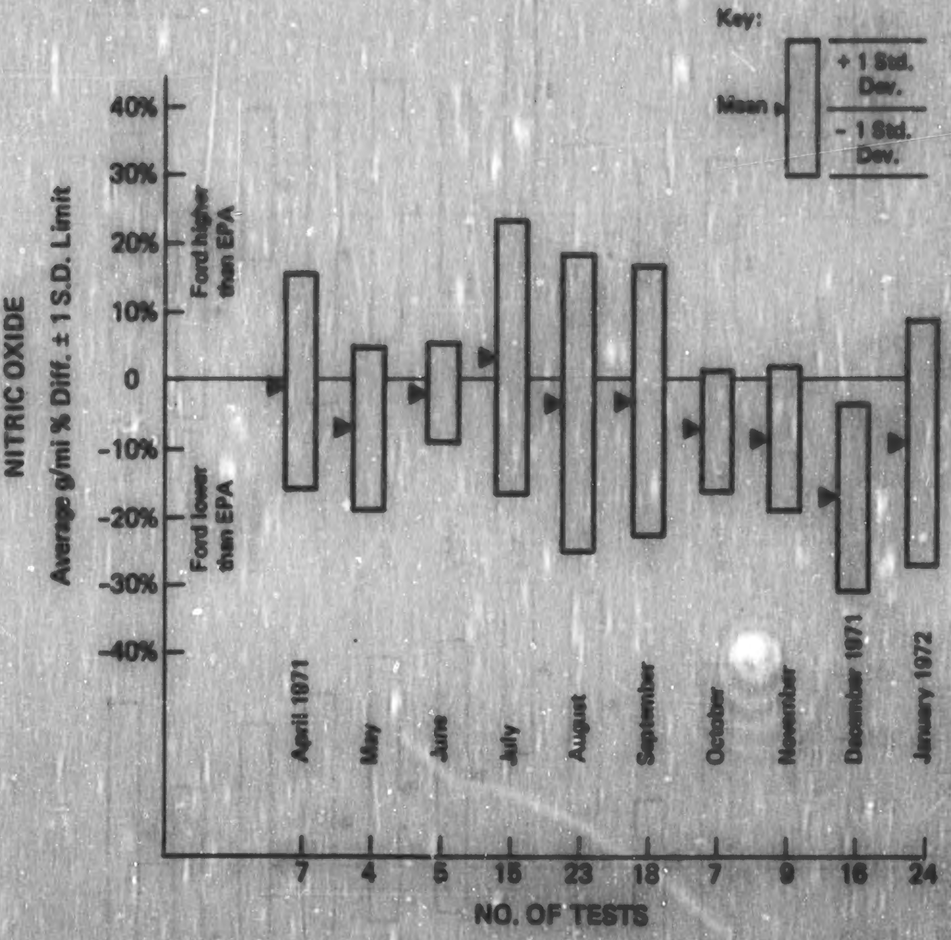

FIGURE 6 Interlap comparisons between EPA and Ford, nitric oxide.

The CVS sample collection method involves dilution of the exhaust gases by about a factor of 10. This plus the low 1975-1976 levels gives concentrations in the sample bag that approach the instrumental capabilities. The situation is aggravated since it is necessary to subtract from the concentration measured in this diluted sample the concentration of the same pollutant in a simultaneously collected background sample. Table 7 compares typical sample bag concentrations for 1972 GM prototype vehicles and 1976 GM system development vehicles (12). The most important point is comparison of the concentrations to the instrument sensitivity. The numbers quoted as "maximum sensitivity" are full-scale readings at maximum sensitivity and represent concentration readings at which the signal-to-noise ratio is 100 or less.

Limited evaluations have been made of test repeatability using the CVS-1975 test with vehicles operating near the 1976 emission levels. Figure 7 shows the results of one evaluation based on 16 repetitive tests on a vehicle having very low emissions (12). This test shows that the range of most emission measurements is much higher as a percentage of the mean level than was experienced with the 1972 test system using 1972 emission level vehicles. The hydrocarbons emission range is 67 percent of the mean level, the carbon monoxide emission range is 200 percent of the mean level, while the NO_x measurement range is at a low of 22 percent of the mean level. The coefficients of variation are about 17 percent for HC, 50 percent for CO, and 6 percent for NO_x.

The variation of test results during the cold portion of the test is the largest contributor to the total test variation. Figures 8 through 10 show the relative percent of the total hydrocarbon, carbon monoxide, and NO_x emissions contributed by the various portions of the test--the cold-start bag, the stabilized bag, and the hot-start bag. Both the hydrocarbon and carbon monoxide results show that the cold start is the most important contributor to the total test results. This is not the case with NO_x, where approximately equal portions of the emissions are obtained from the three test bags since NO_x emissions are not controlled by a thermal device (catalytic converter).

TABLE 7 Typical Bag Concentrations PPM

	HC	CO	NO_x
1973			
Stds, g/mi	3.4	39	3
Car values, g/mi	1.54	18.4	3.23
Sample bag, ppm	35.3	572	66
Ambient bag, ppm	3.1	0	0
1976			
Stds, g/mi	.41	3.4	.4
Car values, g/mi	.34	.76	.25
Sample bags, ppm			
Cold transient	22	133	9.3
Cold stabilized	6.1	6	3.5
Hot transient	9.4	12	9.0
Ambient bag (cold)	2	2	.4
Ambient bag (hot)	1.4	1	.41
Typical analyzer Max. sensitivity	4	400	10

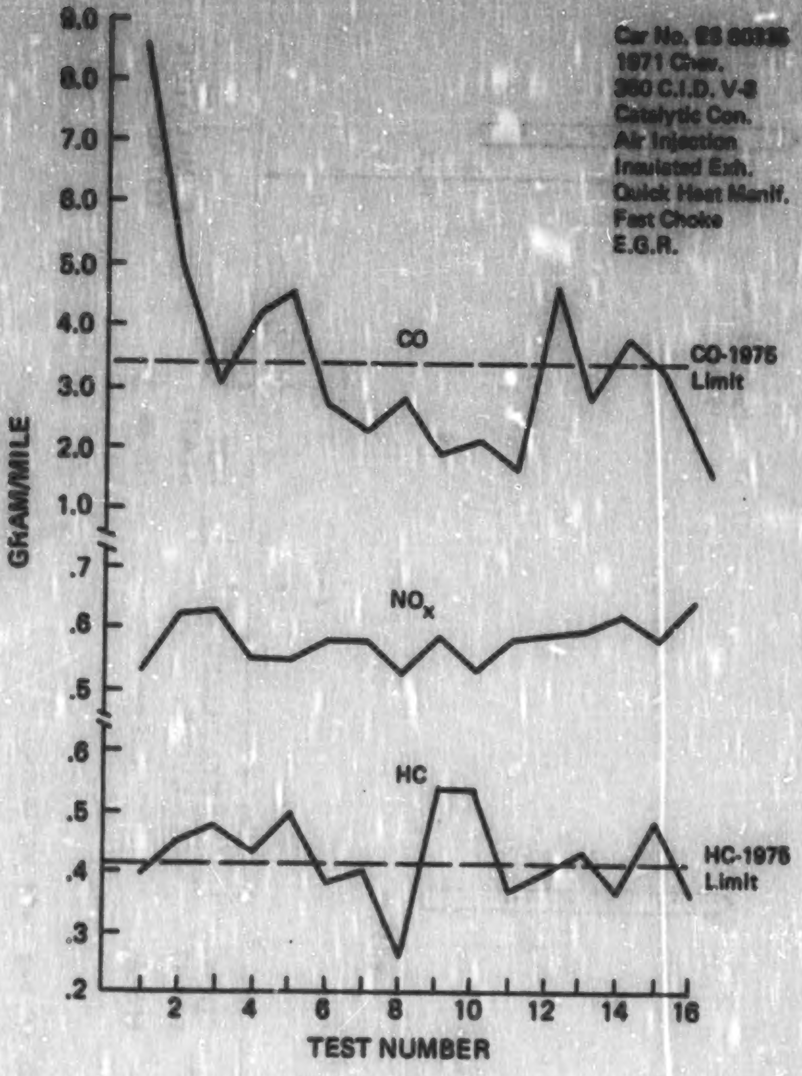

FIGURE 7 1975 EPA test variation (16 test).

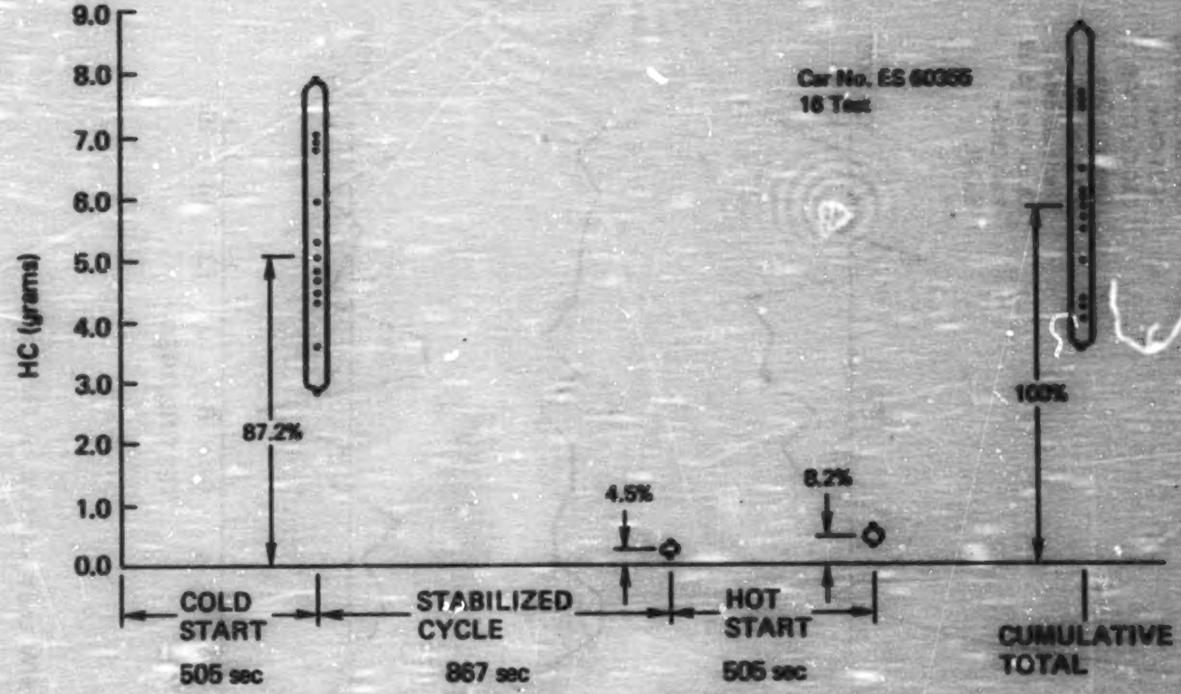

FIGURE 8 1975 EPA HC bag mass variation.

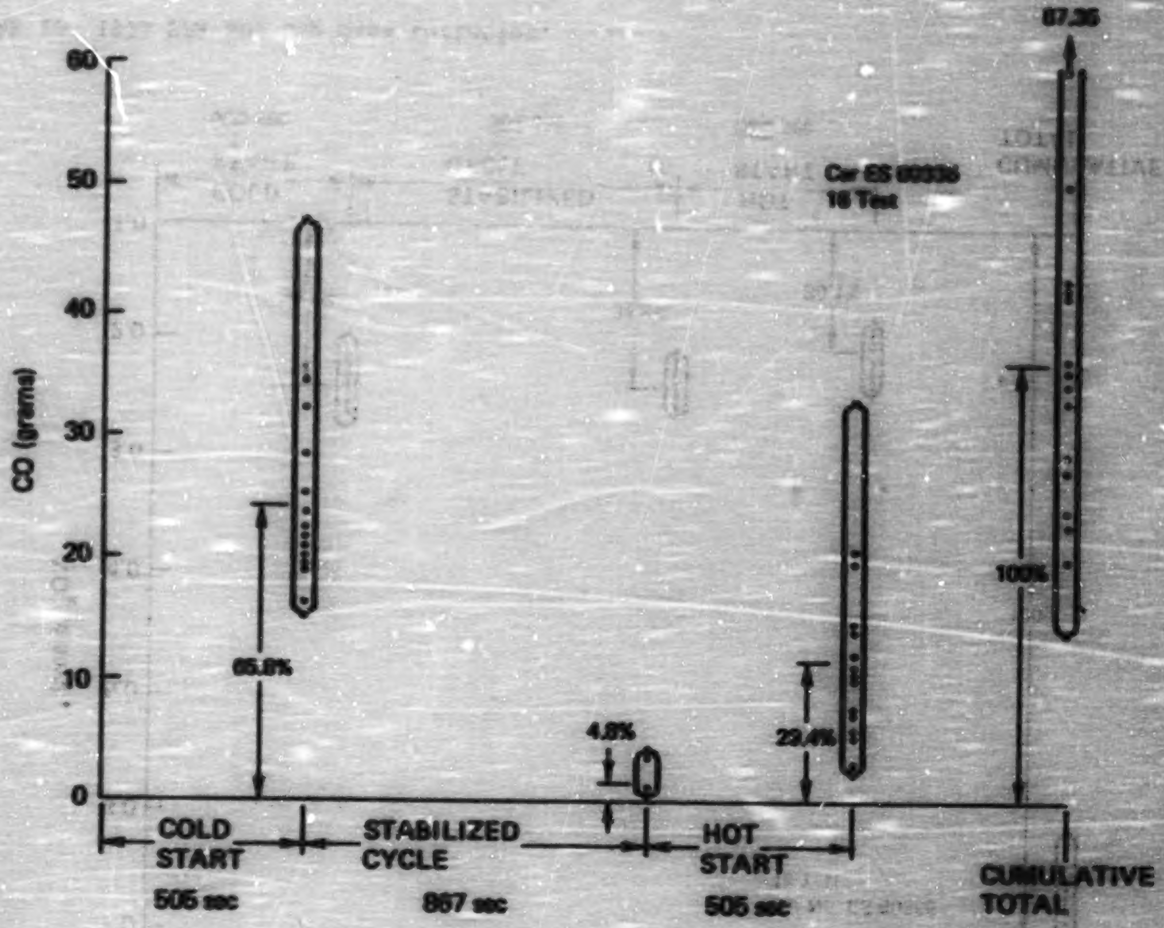

FIGURE 9 EPA CO bag mass variation.

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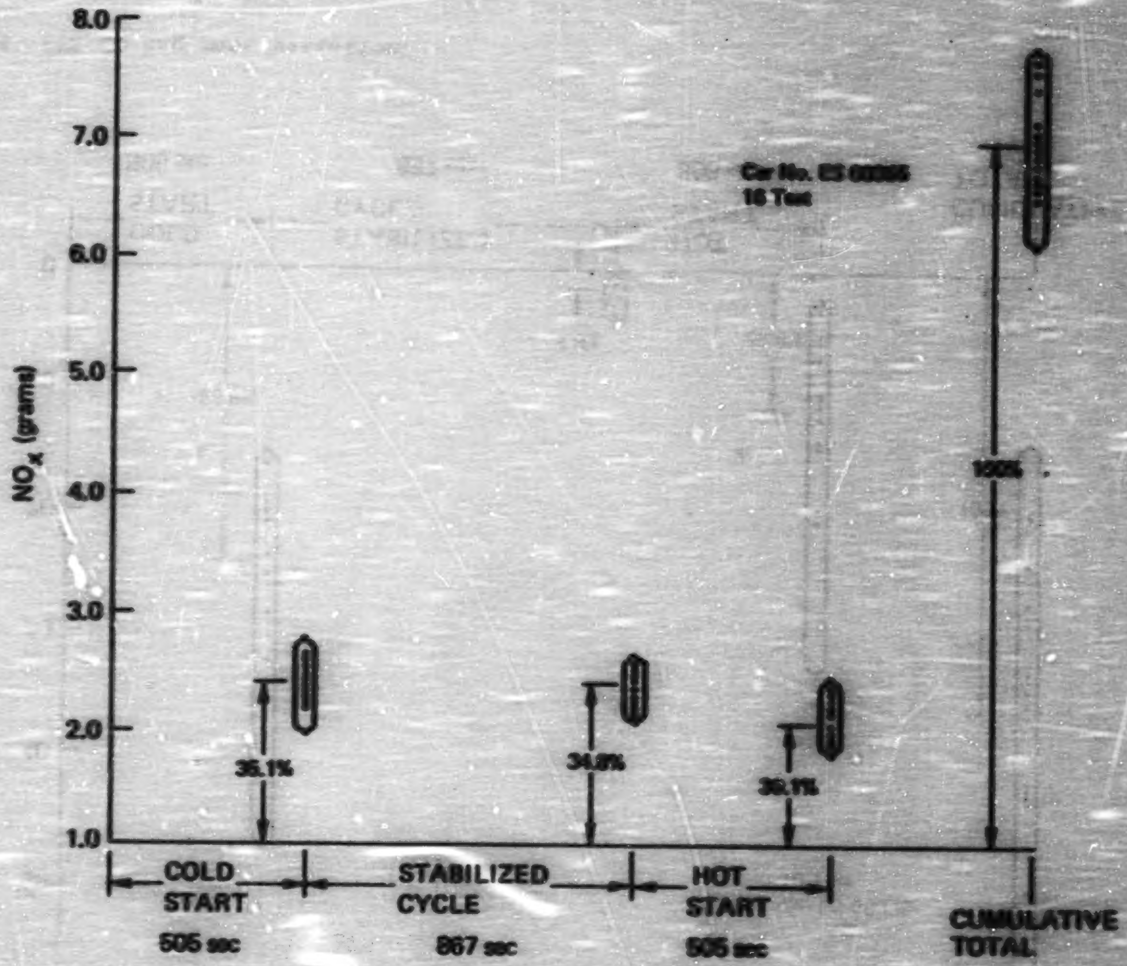


FIGURE 10 1975 EPA NO_x bag mass variation.

It is clear from the above that an individual measurement by the CVS-1975 test on a 1975-1976 car could easily vary from the true value by 50 percent and that no important consequences should be attached to such a single test.

CERTIFICATION PROCEDURE

Title II of the Act requires at least 90 percent reduction, from 1970-1971 levels, of the pollutant emissions from new automobiles of 1975-1976 model years and thereafter. Under the Act it is unlawful to offer for sale new motor vehicles that are not in conformity with Federal regulations.

To enforce the provisions of the Act, EPA has established, in addition to emission standards and the CVS-1975 test, regulations prescribing requirements a manufacturer must meet before the EPA will grant a Certificate of Conformity. The requirements, called Certification Procedures, are summarized as follows.

Prior to the beginning of each model year, the automobile manufacturers apply to EPA for a Certificate of Conformity for each model they wish to produce for that year. In advance of production, the manufacturers are required to provide the EPA with extensive test data demonstrating the effectiveness of the vehicle's emission control system and the ability of this system to remain effective over the "useful life" of a vehicle. "Useful life" is defined in the Act, for light-duty vehicles, as 5 years or 50,000 miles, whichever first occurs. Emissions data are obtained by the CVS-1975 test. In addition to the submission of test data on the prototype test vehicles the manufacturers are required to deliver the test vehicles to the Federal Testing Laboratory at Ann Arbor, Michigan, for confirmatory testing.

The regulations require a manufacturer to test two separate fleets of prototype vehicles that will represent the models to be sold to the public. One fleet, known as the emission-data fleet, is used to determine the emissions of relatively new vehicles. The vehicles in this fleet are driven for 4,000 miles to break in the engine and stabilize emissions. The emissions are then measured. The second fleet, known as the durability-data fleet, is used to determine the capability of the emission-control system to keep emissions within the standards over the expected "useful life" of the vehicle. The vehicles in this fleet are driven for 50,000 miles and tested for emissions every 4,000 miles. The procedure for mileage accumulation is the Durability Driving Schedule over a modified AMA route specified in the regulations. The maximum speed is 70 mph and the average is 30 mph.

One major engine tuneup to manufacturer's specifications may be performed on durability vehicles at 24,000 miles (on vehicles with 150 CID or less, at 12,000, 24,000 and 36,000 miles). The replacements and adjustments allowed are detailed in the regulations.

Allowable maintenance on emission-data vehicles is limited to the adjustment of engine idle speed at the 4,000-mile test point. Emission tests must be run before and after any vehicle maintenance that may be reasonably expected to affect emissions.

Emission-deterioration factors are determined from the durability-data fleet emission test results, omitting emissions data at zero miles. Separate deterioration factors are determined for HC, CO, and NO_x and for each engine-control-system combination. The emission test results, at 4,000 miles, for each emission-data fleet vehicle are then multiplied by the appropriate deterioration factor to give adjusted emissions for each vehicle. The adjusted emissions are compared to the standards, and every test vehicle from an engine family must comply with the standards before any vehicle in that family can be cerfitied. (Similar regulations govern evaporative emissions.)

The primary objective of the Act requires that the Certification Procedures represent, as nearly as possible, the wear, deterioration, and stresses that a car is subjected to in normal usage. The equivalence of the CVS-1975 test to real life has already been discussed; consequently, the question reduces to whether the Durability Driving Schedule and allowed maintenance are equivalent to real-life conditions.

EPA wants the durability test to be sufficient to establish that the emission-control systems will perform in the hands of the customer. The allowable maintenance in the durability test--one major tuneup in 30,000 miles--was selected to make the test tough and realistic.. EMA's argument is that vehicle owners neglect their vehicles until they fail to run or run poorly. EMA believes that in real life much more frequent maintenance will be necessary for 1975-1976 systems, and the Act (Section 207(c)(3)) requires the manufacturers to furnish written maintenance instructions with each vehicle. Manufacturers are in agreement that more maintenance will be necessary for vehicles in use than is allowed during certification (3). This is supported by the fact that manufacturers are now requiring more maintenance as a condition of warranty than they were allowed in the Certification Procedure.

All of the manufacturers also agree that the testing during the Certification Procedure is far from sufficient to establish that the product will perform as the customer expects, not only with regard to emissions but also with regard to factors such as safety, driveability, maintenance, etc. The manufacturers all perform many other tests, but none of them wants a more complicated official procedure.

The driving modes specified in the mileage accumulation do not represent all the possible modes encountered in real life. There are some, not included, such as sustained operation at high engine power and long decelerations that will severely stress catalyst control systems. Ford believes the driving does not provide enough mechanical stress on the catalyst, especially if the driving is carried out on an automatically programmed dynamometer, the usual system to accelerate mileage accumulation. The vehicles are stopped only for tests every 4,000 miles. In real life, vehicles stop much more frequently and a simple calculation indicates that the catalyst will cool down and heat up about 600 or 700 more times in 50,000 miles of normal use than in certification. The New York City Department of Air Resources (11) has also pointed out that the Certification Procedure does not represent actual driving conditions because of insufficient allowance for the effect of accessories, e.g., air conditioners.

Durability of the catalysts, major components of most control systems in 1975-1976, is extremely important. These components are one of the most sensitive and furthermore, are essential to attain the emission levels required. The EPA Administrator has eased the durability requirement by indicating that he intends to allow the replacement of catalysts at least once during 50,000 miles of vehicle operation if such replacement is necessary to the continued effectiveness of emission control systems over the useful life of the vehicle. In discussing the law he cited Section 207(c)(3) of the Act.

We know that vehicles in the customer's hands will not be driven according to the CVS-1975 test procedure, will not be driven according to the Durability Driving Schedule, will probably not receive the maintenance specified by the manufacturer and therefore that emissions may be different than those measured in obtaining Certification. There are no hard data that say real-life emissions will be higher or lower for 1975-1976 vehicles than those obtained during certification but the experience with the present vehicles indicates that they will be worse (see Deterioration).

SHORT EMISSION TESTS

It is impractical to determine the emissions from a large number of cars by the official CVS-1975 procedure since it requires a 12-hour temperature equilibration prior to the actual 41-minute test. Consequently, a number of short emission tests have been developed and they are designed principally for checking the emissions from cars in use, but some of them can also be used as simple pass-fail tests on the assembly line, as production control tests on every car, as warranty tests on every car, and as diagnostic aids. Since even partial temperature equilibration of a vehicle takes considerable time and since the engine is already hot when the vehicle arrives at the test facility, short emission tests are hot-start tests.

Sixteen short emission tests have been proposed and they are described in Appendix B. A comparison of the nine most commonly used tests is given in Table 8.

TABLE 8 SHORT EMISSIONS TESTS

Test	Cycle Test Time	Total Inspection Time	Number of Technicians	Equipment Required	Application
7-mode hot cycle	137 sec	197 sec	2	Exhaust analyzers and dynamometer	Calif. surveillance and end-of-line testing
CVS hot-start	505 sec	—	—	ditto, plus CVS system	—
EPA short cycle	124 sec	—	—	ditto	—
GM exit cycle	60 sec	120 sec	2	exhaust analyzers and dynamometer	inactive
Ford 0-40 Accel.	45 sec.	105 sec.	2	ditto	inactive
NJ ACID cycle	60 sec	180 sec	2	ditto, plus CVS system	under development for phase 2 in NJ.
Keymode cycle	60 sec	120 sec	2	exhaust analyzers and dynamometer	DMVI Washington, D.C.
EPA steady-state cycle	60 sec	120 sec conc. 180 sec CVS	2	ditto plus CVS system	under development
Idle test	n.a.	less than 60 sec	1	exhaust analyzers	DMVI NJ., Calif. road side, assembly line

IMPACT OF COLD-START EMISSIONS AND THE LACK OF REPEATABILITY

The description of the CVS-1975 procedure, Figures 2 and 3 and Figures 8 to 10, emphasize that the emissions during the first 2 minutes dominate the total emissions of HC and CO during the test at the level of the 1975 or 1976 standards. This predominance of the emissions during cold start adds to the lack of repeatability since failure of the car to start immediately at the beginning of the test will cause excessive emissions. Because of the lack of repeatability, no test will guarantee that 100 percent of a group of cars meets specified standards. If every car were tested by the official CVS-1975 procedure a significant number of cars having emissions above the standards would pass and an equal number meeting the standards would fail. If the test were repeated the group that passed and the group that failed would each contain a significant number of cars different from the first test.

This lack of repeatability, primarily caused by variations in the vehicle and its emission-control system, is characteristic of all exhaust-emission test procedures. If one test procedure will not pass and fail the same cars when repeated, then two different test procedures cannot be expected to pass and fail the same cars. Obviously, any hot-start test will not measure the emissions that dominate the results obtained with the CVS-1975 test, and consequently the lack of agreement between tests increase when one is the CVS-1975 and the other is hot-start.

The situation is illustrated by Figures 11 and 12. Figure 11 plots hydrocarbon emissions measured by the 7-mode hot-start procedure against emissions measured by the official 1972 Federal CVS cold-start procedure for a group of Chrysler cars (14). If the tests could be used interchangeably with complete confidence, all the data points would fall either in the "pass both" or "fail both" quadrants. This is far from the case, and this figure illustrates that different test methods do not pass and fail the same cars when univariate correlation is used. Figure 12 is a similar chart where percent CO determined by a

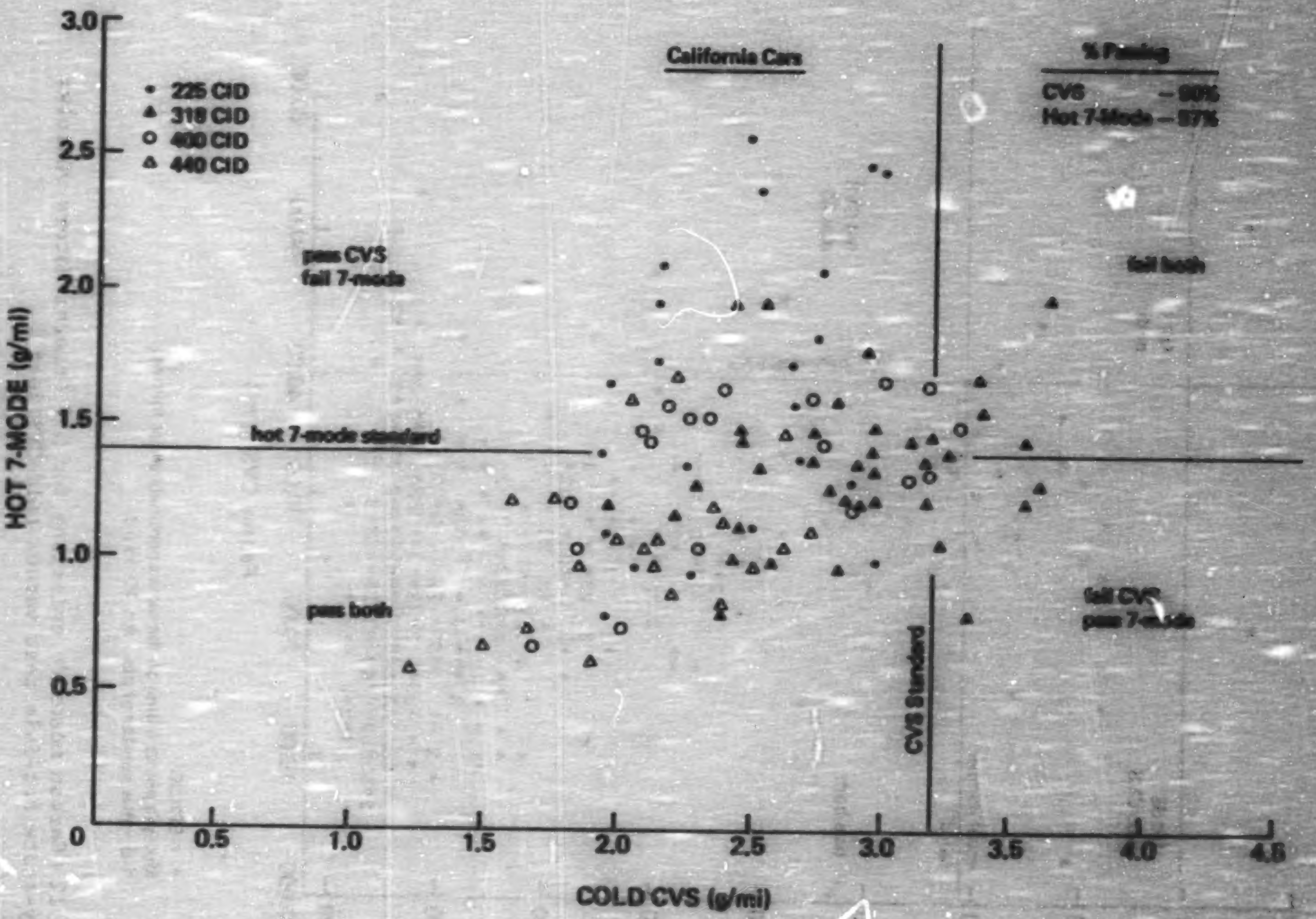
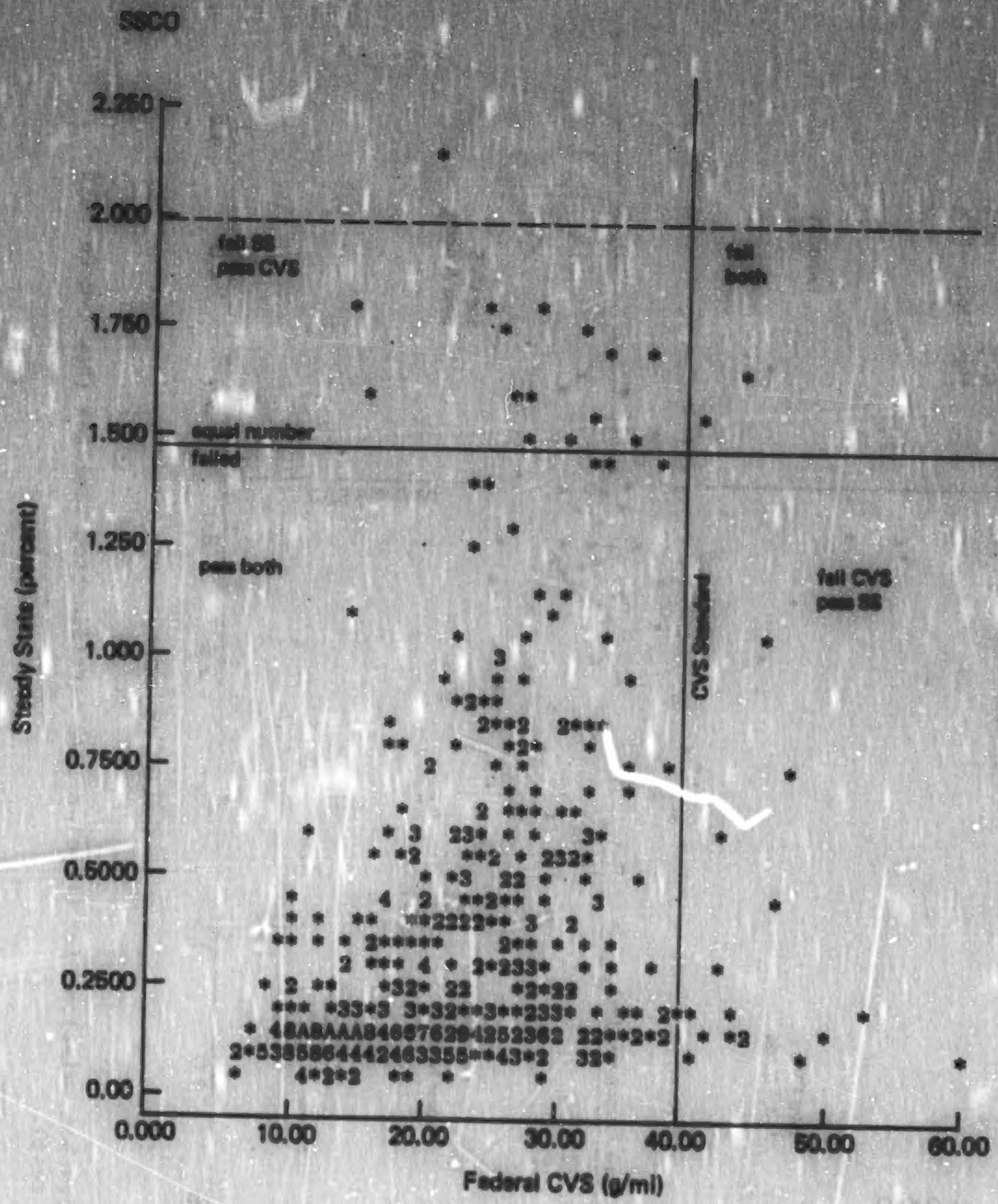


FIGURE 11 Hydrocarbon emissions for Chrysler 1972 certification vehicles (hot 7-mode test versus cold CVS test).



* = EPACO
Multiple points falling on the same coordinate are as follows:
1-9 = that number of pts. A = 10-19 pts.

FIGURE 12 Carbon monoxide emissions for 557 General Motors vehicles (steady-state hot-idle test versus cold CVS test).

steady state (hot-idle, no-load) test is plotted against g/mi CO determined by the Federal CVS cold-start method for 557 GM cars (15). Again, univariate correlation is used in these data. Since there is no established standard for this steady-state test, the pass-fail line for the hot test has been chosen to fail the same number of cars as the CVS-1972 test. This corresponds to a suggestion often made. Note, however, that although the same number are failed by both methods on this basis, only 2 out of 19 were failed by both tests. The significance of this is emphasized by the fact that any emissions test of all the cars in use (for warranty, perhaps) or of all the cars off the assembly line must be a hot-start test.

DIAGNOSTIC TESTS

Repair or adjustment by mechanics is the only operation which directly reduces the emissions from cars in use. Consequently, even though inspection lanes select the vehicles needing repair and in some cases obtain results to assist the mechanic, the mechanic must have tests to locate the malfunction and assure him that it has been corrected. These are called diagnostic tests and they can be used not only to determine corrective action but also to indicate the preventive maintenance which is advisable. Various types of diagnostic tests are listed in Table 9. The techniques and equipment for all of these tests are sufficiently well developed for 1975-1976 requirements except those listed under the heading of NO_x catalyst. At the present time, there are no low-cost instruments for the measurement of nitric oxide (NO) suitable for use in the service industry and there are no known garage-type methods of evaluating the activity of an NO_x catalyst.

A test (16) for the activity of the oxidation catalyst can be performed by shorting out one spark plug of a cylinder feeding the converter. The catalyst bed is protected from over-temperature by limiting the time of mis-fire to 60 seconds. This introduces a known high quantity of hydrocarbons to the catalyst, and measurement of

TABLE 9 DIAGNOSTIC TESTS

PCV System

1. Measurement of crankcase pressure
2. Measurement of PCV valve flow

HC/CO Catalyst

1. Exhaust
2. Functional tests on catalyst activity
3. Inspection of pellet-type catalyst levels vs. monolithic catalyst cartridge

NO_x Catalyst

1. Exhaust gas nitrogen oxide (NO) measurement
2. Catalyst activity test
3. Inspection of pellet-type catalyst level or monolithic catalyst cartridge

Air Pump

1. Inspection of air flow
2. Inspection of filter, plumbing, etc.
3. Functional tests on check valves and anti-backfire valves

Ignition

1. Oscilloscope analysis
2. Electronic simulation of engine conditions producing misfires
3. Exhaust gas hydrocarbon measurement

Carburetion

1. Exhaust gas carbon monoxide (CO) and hydrocarbon (HC) measurements
2. Function checks on the operation of carburetor linkage
3. Function tests on the operation of mixture control circuits and systems
4. Oscilloscope analysis

EGR System

1. Functional tests on components such as the EGR valve
2. Measurement of EGR flow
3. Visual inspection of deposits

TABLE 9 (cont.)

Other

1. Heat riser valve operation
2. Air filter restriction

exhaust hydrocarbons by garage-type analyzers gives an excellent measurement of catalyst activity. Measurement of HC is a better indication of catalyst activity than measurement of CO because HC conversion relies more upon catalyst surface activity and the amount of surface available. Tests show that this test is more sensitive than 7-mode cycle hot tests in the detection of changes in converter efficiency. The test has the advantage that it can isolate engine variables from the catalyst evaluation.

Unfortunately, the above catalyst test does not determine the light-off time of the catalyst and therefore does not determine whether the system is meeting the 1975-1976 standards in the legal sense since cold-start emissions are so predominant. Development of a short test (necessarily hot start) to determine light-off time or temperature appears to be difficult because of the inherent logical contradiction.

CLASSIFICATION OF MAINTENANCE METHODS

Maintenance Methods for Probable 1975-1976 Cars

Methods for ensuring proper maintenance of the control systems that will probably be manufactured as 1975-1976 models fall into three classes:

1. Requiring the service industry to adjust each car to manufacturer's specifications when performing any maintenance.
2. Periodically testing all cars and designating for adjustment or repair those not meeting preselected standards.
3. Periodically testing all cars and performing any necessary adjustments or repairs.

The first method is based on the fact that the manufacturer's specifications for 1975-1976 vehicles will probably represent adjustment to minimum emissions with acceptable performance and safety. The manufacturer is required (Section 207(c)(3) of the Act) to furnish written instructions with each vehicle for proper maintenance of the emission control system. Present adjustments are often made to obtain high performance, which may increase emissions; and even adjustment to manufacturer's specifications does not represent minimum emissions for many cars now in use.

The principal variations in the second method are how much of the work is done in state-owned and how much in privately-owned facilities, the testing procedure used, testing frequency, pass/fail standards, provision fot retesting after repair/adjustment, and disposition of vehicles that cannot meet the standards.

The third method is mandatory maintenance at specified intervals, and adjustments would again be to preselected specifications. Preventive maintenance would be easy to include and particularly effective because of the regular maintenance intervals.

Other Possible Methods

The other methods for ensuring the maintenance of cars in use are probably feasible only if engineering changes, which do not seem likely by 1976, are made. They are as follows:

4. Repair at the time of failure of any important emission control device based on the presence of devices which signal the failure not only to the driver but also to the traffic officer.

5. Repair at the time of failure of any important emission control device based on the use of control systems designed to noticeably degrade the vehicle performance when an important component fails.

6. Prescribed maintenance at predetermined intervals. This method would require strict quality control of the manufacturing process so that essentially every car was held to a configuration proved to give low emissions in actual use.

4 FACTORS AFFECTING FEASIBILITY

PROBABLE 1975-1976 CONTROL SYSTEMS

Maintenance which will be required for 1975-1976 cars will be determined by the emission control systems and the individual parts of these systems. The manufacturers have considered many systems including alternative power sources but it is certain at this time that nearly all 1975 and 1976 cars will have conventional spark-ignition internal combustion engines (IC). A few will have Wankel, diesel, or stratified-charge engines but none of these will be produced in quantities that affect the feasibility of meeting the standards in use. The major components of control systems that are being considered for the IC engines are

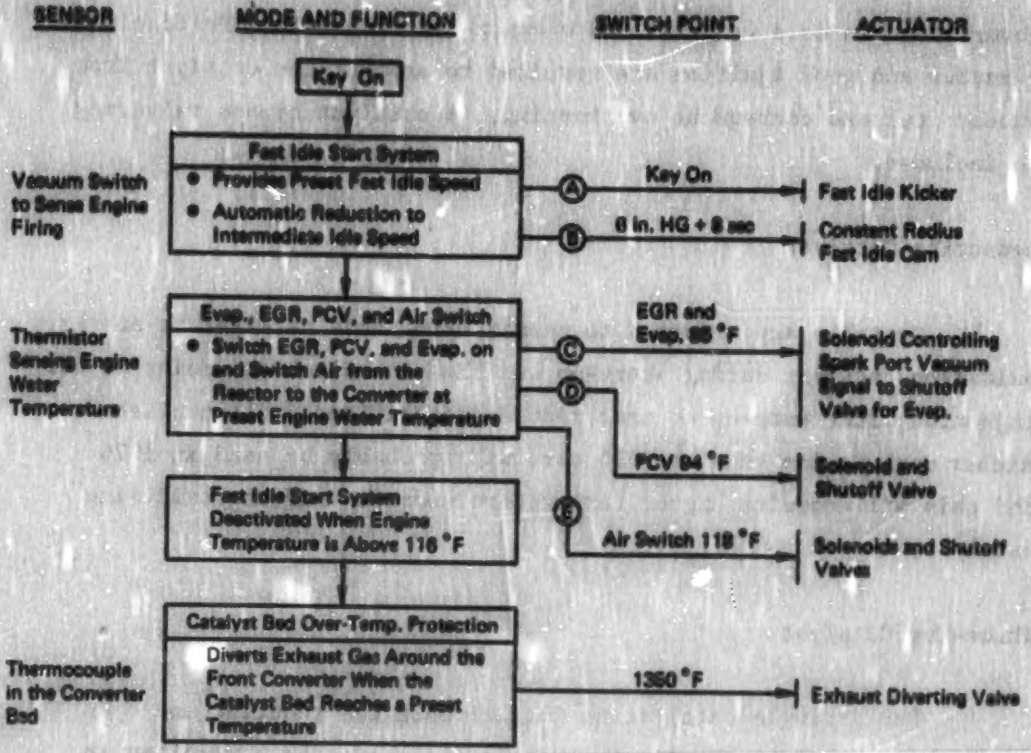
Oxidation catalyst
Reduction catalyst
Three-way (single-bed) catalyst
Exhaust manifold reactor
Exhaust gas recirculation

Associated with each of these primary approaches to emissions control is a multitude of control valves, quick warm-up systems, protection devices, control circuits, etc. Figure 13 illustrates the complexity and precision of operation that will be required (17).

No attempt will be made in this report to describe any of the control systems, since this is the responsibility of the Panel on Emission Control Systems and since for this report only a list of parts required for maintaining these cars is needed. However, a few comments on special problems will be included.

Oxidation Catalyst

Detergent fuels low in lead, sulfur, and phosphorus will be required. Start-up emissions are minimized by a fast-acting choke


SENSOR
MODE AND FUNCTION
SWITCH POINT
ACTUATOR
Key On
Fast Idle Start System
● Provides Preset Fast Idle Speed
● Automatic Reduction to Intermediate Idle Speed
Vacuum Switch to Sense Engine Firing
A
Key On
Fast Idle Kicker
B
6 in. HG + 8 sec
Constant Radius Fast Idle Cam
Evap., EGR, PCV, and Air Switch
● Switch EGR, PCV, and Evap. on and Switch Air from the Reactor to the Converter at Preset Engine Water Temperature
Thermistor Sensing Engine Water Temperature
C
EGR and Evap. 85 °F
Solenoid Controlling Spark Port Vacuum Signal to Shutoff Valve for Evap.
D
PCV 94 °F
Solenoid and Shutoff Valve
E
Air Switch 118 °F
Solenoids and Shutoff Valves
Fast Idle Start System Deactivated When Engine Temperature is Above 116 °F
Catalyst Bed Over-Temp. Protection
Diverts Exhaust Gas Around the Front Converter When the Catalyst Bed Reaches a Preset Temperature
Thermocouple in the Converter Bed
1350 °F
Exhaust Diverting Valve

Concept Emission Package AC Sequence of Controller Events First Mode of CVS Driving Cycle

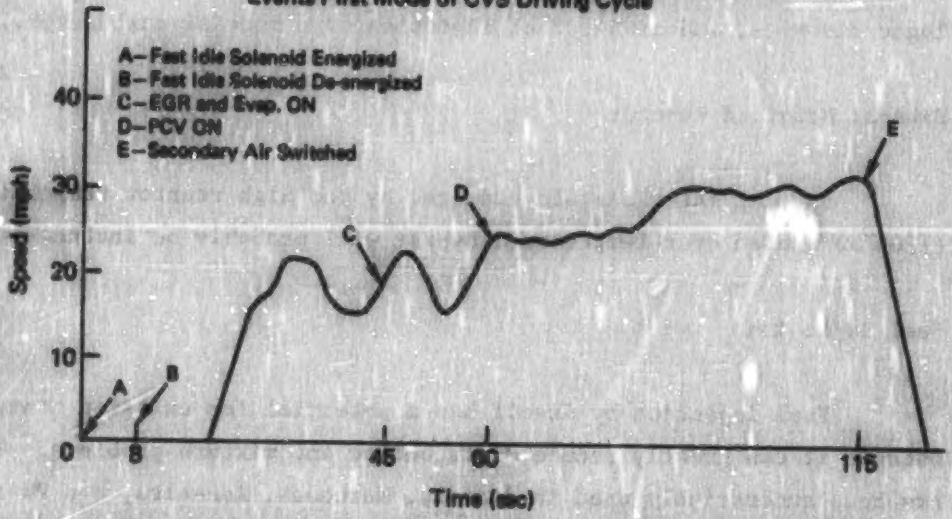


FIGURE 13 Concept emission package ac control module logic diagram.

(overridden in cold weather) and a quick-heat manifold. Precise carburetion and good ignition are required to protect the catalyst from excess fuel and consequent overheating. A catalyst bypass valve may be included.

Reduction Catalyst

Controls are required to permit using this catalyst as an oxidation catalyst during start-up and then to switch the point of air injection after warm-up so that reducing conditions are established. Richer carburetion than on 1975 cars will probably be used in 1976 and this will require higher temperature operation of the oxidizing catalyst.

Three-Way Catalyst

For a single catalyst to fulfill both the reducing and oxidizing functions, the air-fuel ratio (A/F) must be controlled in a narrow range close to stoichiometry. Figure 14 shows the narrow A/F range required by one three-way catalyst (18) for good simultaneous conversion of both NO_x and HC-CO. Controlling the A/F will require a feedback loop probably consisting of an oxygen sensor, electronic logic circuits, and either fuel injection or a special carburetor.

Exhaust Manifold Reactor

Special materials are required by the high reactor temperature (1800°F) and an over-temperature bypass will probably be included.

Fuel Injection

Fuel injection by itself has a potential for emission control because it can greatly reduce distribution and mixture problems. It has been successfully used in diesels, Mercedes, Renaults, and VW's.

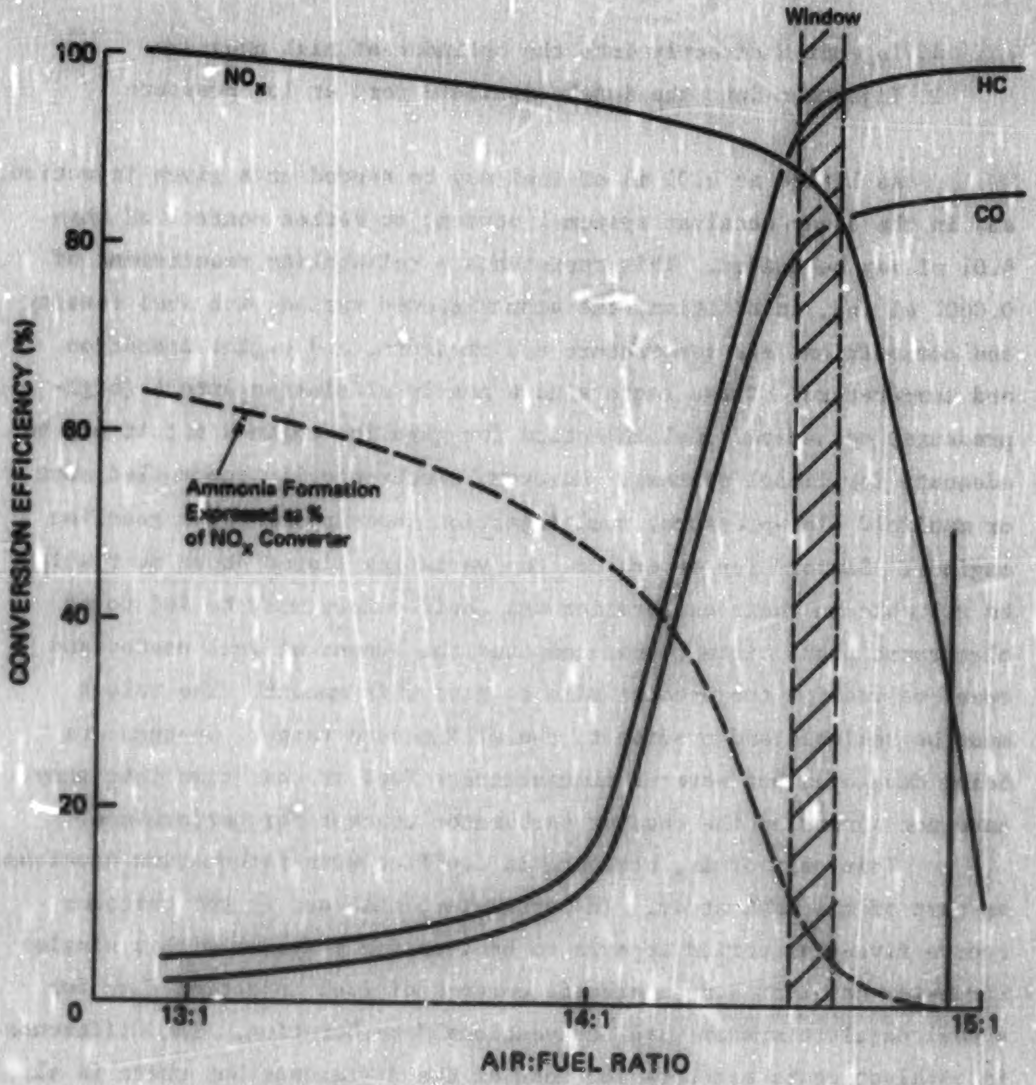


FIGURE 14 Principle of operation for 3-constituent conversion with a noble-metal catalyst.

It can take two basic forms:

1. Injection directly into the cylinder at high pressure
2. Injection into the intake manifold port at low pressure

As little as 0.01 ml of fuel may be needed on a given injection, and in the 3-way catalyst system 1 percent or better control of this 0.01 ml may be needed. This represents a reliability requirement of 0.0001 ml and, in addition, the amount needed varies with fuel density and composition, air temperature and pressure, and engine operation and temperature. These factors have nearly eliminated direct (high-pressure) mechanical fuel injection for gasoline engines but it may be adequate for diesel systems. However, electronically controlled port or manifold (low-pressure) fuel injection shows promise for gasoline engines. Sensors for several of the variables listed above must all be reliable in their calibration and their output must be fed to an electronic logic circuit that computes the amount of fuel needed and opens valves for the precise time to give this amount. The valves must be reliable and precise to the millisecond range. Systems are being developed but several manufacturers feel at this time that they have not surpassed the cheaper carburetor concept for performance.

This opinion is, however, in conflict with information developed as part of the CMVE study. In particular, the cost to the customer over a five-year period appears to be less for a system with a single three-way catalyst and electronic control of fuel injection than for a dual catalyst system with "conventional" carburetion. The difference in catalyst costs accounts for most of the difference but there is also a fuel differential. Actually, the carburetors are becoming more and more complicated, and it is no longer clear that they will remain cheaper than fuel injection. If close control of air-fuel ratio becomes necessary in the dual-catalyst systems also, then electronically controlled fuel injection will probably be superior on all counts.

Wankel Engine

Because the Wankel engine is somewhat higher in HC, similar in CO, and lower in NO_x emissions than a conventional IC engine, similar control systems are required. The small size of the Wankel engine leaves more room for these controls in the engine compartment and the relatively uniform pressure in the exhaust makes it somewhat easier to treat.

Diesel Engines

Small diesel engines with fuel injection into a precombustion chamber (Mercedes 220D) could probably meet the 1975 standards. NO_x values about twice the 1976 standard are achievable and this could be reduced by EGR automatically controlled by the power demand. Diesel engines have good durability and the maintenance problems would most likely concern only the fuel injectors and the EGR control system.

Stratified-Charge Engines

Carbureted three-valve stratified-charge engines (Honda) in compact prototype cars have met the 1975 standards for 50,000 miles and have had NO_x emissions within about a factor of 2 of the 1976 standard. These values were attained without EGR and catalysts. These engines are conventional except for the cylinder head, intake and exhaust manifolds, and the carburetor. It seems probable that this concept can be applied to larger engines and that this concept will be able to attain the 1976 standards. The low deterioration rates during the 50,000-mile tests indicate that these engines should maintain their low emissions in actual use. Maintenance should present no unusual problems.

DURABILITY OF PROBABLE CONTROL SYSTEMS

Durability data that are significant in evaluating the feasibility of ensuring that cars in use meet the 1975-1976 standards are not available. The fact that durability data for even one car for 50,000 miles under the fuel and maintenance conditions prescribed by the Certification Procedure are not available for either the 1975 or 1976 models is in itself significant, since durability for the "useful life" specified in the Act has not been proved for the proposed control systems.

Table 10 lists all of the data that could be obtained on vehicles with emissions below the 1975 standards for more than 10,000 miles before May 1972.* It takes considerable time to generate such data, therefore extended mileage results do not represent the very latest system formulations or catalysts. System failures also contribute to the small number of cars with extensive life. Also, some of the test results reported are based on test methods other than the current Federal durability cycle and CVS test. In most cases such results are better than they would be on the official test or in customer service. Eleven tests have been reported under the 1975 standards. Of these, six were under the standards at 20,000 miles and one at 30,000 miles.

Table 11 shows test results reported under the 1976 standards at any mileage. None could be considered durability tests because 2784 is the highest mileage. System development is just getting under way for the 1976 standards and this partly accounts for the lack of durability data.

There seems to be little doubt that the catalysts are the least durable components in the 1975-1976 systems. Gradual deterioration of activity over 50,000 miles should be held to a factor of 2 in order to comply with the standards, since most engineering targets for new-car emissions are above 1/2 of the standards. The manufacturers have

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*Data that became available later in 1972 do not significantly affect the conclusions of this section.

TABLE 10 DURABILITY DATA FOR 1975 CONTROL SYSTEMS

Test			Vehicle		Catalyst			Emissions, g/mi			
Co.	Mo/Yr	Type[a]	Type	No.	Type[b]	No.	Mileage	HC	CO	NO_x	Comments
Chrysler	-	-	-	698	ENM	-	23,000	0.37	1.70	2.55	Manual by-pass
Chrysler	-	-	-	333	ENM	-	21,729	0.40	1.80	2.40	Unleaded Indolene
Chrysler	-	-	-	385	ENM	-	20,000	0.26	2.84	1.56	
Brit. Le.	-	-	-	-	ENM	-	11,450	0.34	2.08	1.65	0.014 gPb/gal
Volvo	-	-	-	-	ENM	PTX416	25,344	0.24	2.45	1.82	No Pb[c]
Am.Motors	-	-	-	-	DBP	SN/229	32,000	0.39	3.04	1.50	Pb below 0.024 g/gal.
Engelhard	-	-	-	-	ENM	PTX-5(1)	25,260	0.39	3.3	<3.0	Pb free ashless oil
Engelhard	-	-	-	-	ENM	PTX-5(2)	12,030	0.24	2.6	2.2	Pb free ashless oil
Matthey-B	-	-	-	-	M-ENM	AEC-3A	24,000	0.33	2.01	1.33	Pb free fuel
UOP	-	-	-	-	UNP	PZ-1-214-3	15,875	0.30	2.90	3.0	

[a] Type of test procedure FTP(7-mode), 72(CVS cold), 75(CVS cold-hot).

[b] N = noble metal, B = base metal, P = pellet, M = monolith, E = Engelhard, D = Dalco AC, M-B = Matthey Bishop, U = UOP, C = Chemico.

[c] Four standards at some lower mileages.

TABLE 11   DURABILITY DATA FOR 1976 CONTROL SYSTEMS

Test			Vehicle		Catalyst			Emissions, g/mi			
Co.	Mo/Yr	Type[a]	Type	No.	Type[b]	No.	Mileage	HC	CO	NO_x	Comments
VW	5/72	75	—	—	TBM	—	600	0.20	2.01	0.11	
VW	5/72	75	—	—	TBM	—	600	0.25	2.2	0.39	
Chemico	—	—	—	—	CP	—	2784	0.37	1.27	0.32	0.005 g Pb/gal Cat added at 500 mi.

[a] Type of test procedure FTP(7-mode), 72(CVS cold), 75(CVS cold-hot).

[b] N = noble metal, B = base metal, P = pellet, M = monolith, E = Engelhard, D = Delco Ac, M-B = Matthey Bishop, U = UOP, C = Chemico.

indicated difficulty in achieving such low factors and, as stated above, no car has stayed below the standards for 50,000 miles under conditions that adhered strictly to the Certification Procedure when operated on fuel containing the level of impurities allowed by the proposed Federal rules. Recent data are somewhat contradictory. Figure 15 shows the result of a durability run completed in August by American Motors. The deterioration factor is 3.9 and the vehicle was exceeding the HC standard at 30,000 miles. Fuel containing less than 0.02 g/gal. of lead and a catalytic converter almost double the usual size was used, but even so the standard was exceeded.

In contrast UOP has recently obtained encouraging data (19). A base-metal catalyst in a standard 260 in.^{3} GM converter on a 1972 Chevrolet with a 350 CID engine gave emissions of 0.34 g/mi HC, 3.16 g/mi CO, and 2.76 g/mi NO_x at 52,000 miles. The only known deviation from the Certification Procedure was the use of Indolene 30 fuel, which contains 0.017 g/gal. of lead and 0.001 g/gal. phosphorus. With a low platinum catalyst in the same configuration described above and with the same fuel, emissions of 0.1 g/mi HC, 0.84 g/mi CO, and 2.25 g/mi NO_x were obtained at 33,200 miles.

DETERIORATION OF ADJUSTMENTS AND COMPONENTS

Approximately one hundred components and adjustments that could have an effect on emissions were originally listed for the probable 1975-1976 control systems. Of these, about 35 were judged to have such a long life or so little effect on emissions that they were dropped from further consideration. Table 12 lists the remaining items from all of the potential control systems. No one control system would contain them all; however, it will be necessary for the mechanic to maintain all of them. Insofar as possible they are grouped according to their importance. The judgments in the table (described below) are approximate because some items will be new and do not have service histories, whereas the importance of others that do have service

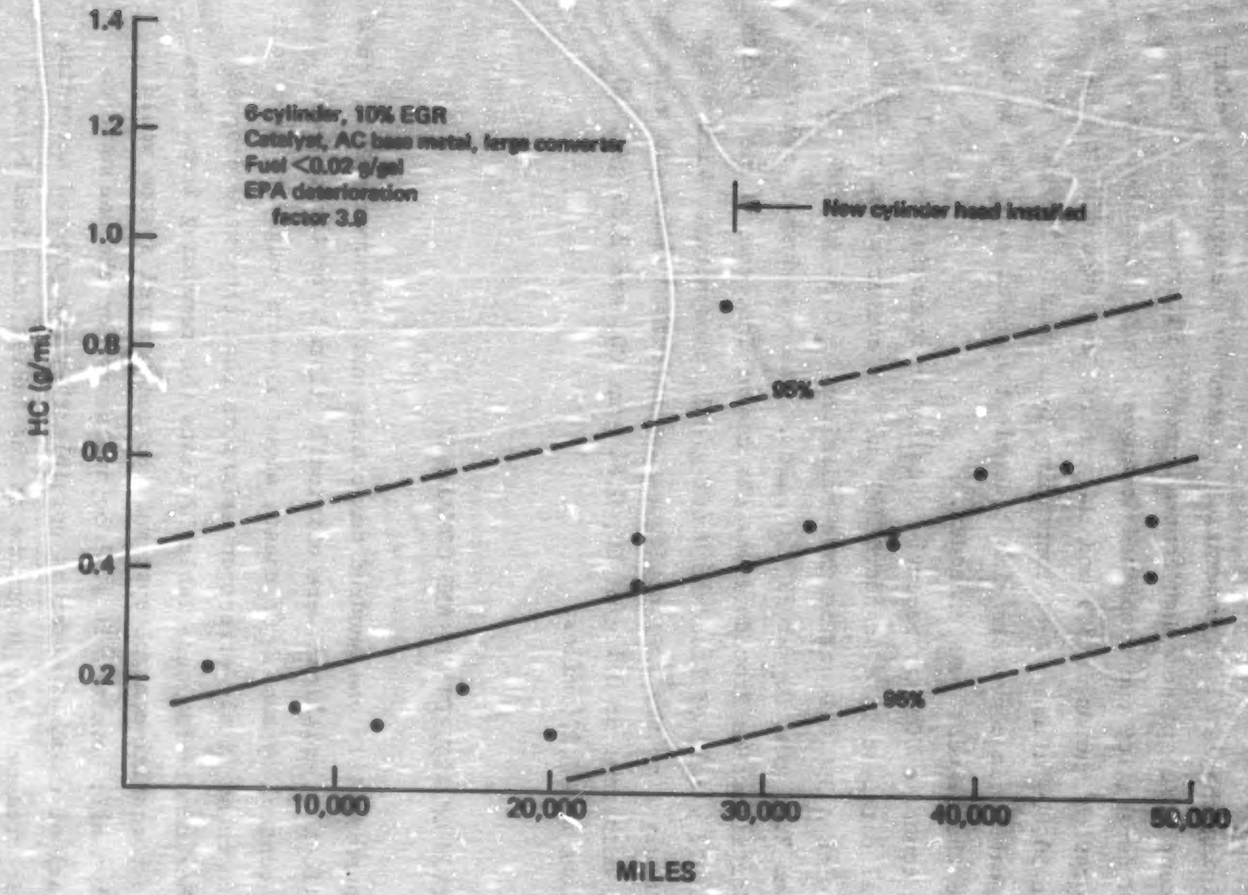

FIGURE 15 Durability run by American Motors.

TABLE 12 EFFECT ON EMISSIONS OF VARIOUS COMPONENTS

NO.	ITEM	HC	CO	NO$_x$	Mean time to Failure, Years	Service Interval, Years
	MAJOR CONTROL EQUIPMENT					
1*	Three-way catalyst (HC,CO,NO$_x$)	H	H	H	2	1
2*	Reduction catalyst (NO$_x$)			H	2	1
3*	Oxidation catalyst (HC,CO)	H	H		2	1
4*	Exhaust manifold reactor	M	M		10	5
5*	Exhaust gas recirculation valve			H	5	1
6*	Air injection pump	M	M	L	5	1
	THESE CAN CAUSE A CATALYST FAILURE					
7*	Catalyst bypass	H	H		5	1
8*	Catalyst thermocouple	H	H		2	1
9*	Exhaust Manifold Reactor bypass	M	M		5	1
10*	Exhaust air diverter valve	M	M	H	8	1
11*	Oxygen sensor for 3-way catalyst	M	M	M	2	1
12*	Electronic feedback control	M	M	M	8	1
13*	Electronic fuel injection	M	M	M	8	1
14*	Fast acting choke	H	H	L	*	1
15	Float valve	M	H	L	5	5
16	Power jet	L	L	L	10	5
17	Fuel pump	L	L	L	5	5
18	Spark plugs	H		M	2	1
19	Plug wires	H		M	3	1
20	Electronic ignition	L	L		10	1
21	Exhaust valve leaks	H		M	10	2

TABLE 12 EFFECT ON EMISSIONS OF VARIOUS COMPONENTS (cont.)

NO.	ITEM	HC	CO	NO_x	Mean time to Failure, Years	Service Interval, Years
THESE CAN HAVE A MAJOR EFFECT ON EMISSIONS						
22	Idle mixture screw	H	H	L	10	1
23	Idle speed screw	L	L		10	1
24	Fast idle speed screw	L	L		10	1
25	Heat riser valve	M	M		8	1
26	Air filter	L	M		2	1
27	PCV valve	M	M		3	1
28	PCV fittings and hoses	L	L		5	1
29	Distributor cap	M			5	1
30	Points	H			4	1
31	Coil wire	H			5	1
32	Air pump belt	H		L	5	1
33	Transmission controlled spark switch			M	5	1
THESE CAN HAVE EFFECT ON EMISSIONS						
34	Coolant thermostat			L	5	5
35	Vacuum advance	M		M	5	2
36	Battery	L		M	3	2
37	Battery cables	L			5	2
38	Voltage regulator	L			5	5
39	Distributor rotor	M			5	1
40	Ignition condenser	M			8	1
41	Coil	H			10	1

70<

TABLE 12 EFFECT ON EMISSIONS OF VARIOUS COMPONENTS (cont.)

NO.	ITEM	HC	CO	NO_x	Mean time to Failure, Years	Service Interval, Years
42	Centrifugal advance	M		M	10	1
43	Intake manifold leaks	M	L		5	2
44	Carburetor metering rods	M	M	L	8	2
45	Carburetor internal vents	L	M	L	10	1
46	Carburetor float	M	M	L	10	10
47	Fuel filter	L	L		2	2
48	Carburetor accelerator pump	L	L		5	5
49*	Quick heat manifold	L	M		10	10
50*	PCV delay solenoid	L	L		5	2
51*	Thermistor to sense coolant	L	L		5	2
52*	Solenoid to activate EGR			M	5	1
53*	Solenoid to activate evap. CS	L			5	1
54	Activated carbon ECS	L			5	5
55	Anti dieseling solenoid valve	L			3	3
56	CAP vacuum advance valve	M			8	5
57	Air injection check valve	M			5	5
58	Air cleaner thermostat	M	M	L	5	5
59	Distributor vacuum control valve	M		M	5	5
60	Gulp valve				5	5
61	Vacuum lines				3	2

histories will be modified by the presence of catalysts. The symbols H, M, and L indicate high, medium, and low emission effects. Starred items will be new to the market. This list illustrates the complexity the mechanic will face. In a period of two years he will face five major new control systems, a completely new engine (Wankel), and at least 14 other new parts. Among this total collection of parts there will be about 20 that must operate about 98 percent of the time if the emissions are to be controlled to a lower level than the 1973 and 1974 cars. Added to this is the complexity that a given item will be different on different makes and models.

In addition to the estimates, by this Panel, of mean time-to-failure and service interval shown in Table 10, data have been obtained from other sources by a questionnaire. Information from four replies is shown in Table 13. Scott Research Laboratories and American Motors put their estimates in terms of mean time-to-failure, Chrysler gave a recommended service interval, and Arco did not include this item in their reply. All the replies were in miles rather than years, but 12,000 miles can be taken as approximately equal to one year (Chrysler specified this) when comparing Tables 12 and 13. The component breakdown is not the same in the two tables, but nevertheless some comparisons are possible. Agreement is fair, but the outside organizations appear to be a little less optimistic about mean time-to-failure than the Panel.

There are no data on the deterioration of the new control systems in use. Consequently, deterioration can only be estimated for items and extrapolated to new conditions for the items and adjustments that have not changed. Evaluation of the effect of deterioration should consider four questions: (1) Which components or adjustments tend to deteriorate the most rapidly? (2) How strongly do they affect emissions? (3) What is their useful life? and (4) What are the synergistic effects? The product of items 2 and 3 gives a measure of the relative importance of the components. Synergistic effects can be important; e.g., losing a plug wire could cause the catalyst to burn out if no overtemperature protection is present or if it is

TABLE 13 EMISSION EFFECTS OF ADJUSTMENTS AND DEVICES

SYSTEM PARAMETER	RELATIVE EFFECT				Mean Time-to Failure (mi)		Service Interval (mi)
	Scott	Arco	Chrysler	Amer. Mts.	Scott	Amer. Mts.	Chrysler
Carburetion							
A/F at idle	M to H	H	M	L to M	15,000	25,000	12,000
A/F main jet	very H	variable	M	L to H	30,000	--	12,000
A/F power jet	--	--	L	M	--	--	12,000
choke	L to H	H	L to H	L to M	25,000	25,000	6 months
heat riser valve	L to M	--	L to M	L	25,000	5,000	6 mo.
altitude compensation	--	--	--	L	--	--	--
leaks intake manifold	M to H	variable	L to H	L to M	50,000	50,000	--
leaks vacuum line	L to H	variable	L to H	L	35,000	50,000	infreq.
air cleaner - plugged	M	H	M	L	20,000	15,000	12,000
Ignition							
misfire--plugs	very H	H	H	M to H	20,000	15-30,000	18,000
misfire--wiring	very H	H	H	M to H	25,000	50,000	infreq.
misfire--cap and rotor	H	H	H	M to H	30,000	50,000	infreq.
basic timing	M	M	L to M	L	15,000	15,000	12,000
automatic spark advance	M	M	L	L to M	25,000	100,000	12,000
Devices							
PCV system	L to M	L	L	L	30,000	15,000	12,000
EGR system	M to H	H	H	L	--	12-50,000	12,000
air pump system	M to H	M	M	L to M	40,000	100,000	12,000
oxidation catalyst	H	H	H	L to H	25,000	12,000	--
reduction catalyst	H	--	H	L to H	25,000	--	--
evaporative control system	M	L	L to H	L	70,000	50,000	12,000
Other							
idle speed	M	--	L	L	15,000	15,000	12,000
burned exhaust valve	H	M to H	H	L to H	90,000	100,000	infreq.
low compression	M	H	L to H	L	60,000	100,000	infreq.

inoperative. Conversely, some failures that cause only small increases in emissions, such as a 2 percent misfire, could be controlled by another system downstream such as the oxidation catalyst without a significant increase in emissions.

The importance of the catalyst cannot be overemphasized because it is the last control before emission to the air; consequently, there is nothing to make up for its failure. As mentioned above, it can compensate for minor malfunctions of other components but so many components and subsystems have been installed to make it work and keep it working that the probability of its working properly for the "useful life" of the car depends on a high reliability of certain key components.

Estimates of the relative effects and of the useful lives of various components have already been included in Tables 12 and 13.

Although there are no data on the deterioration of the projected 1975-1976 control systems in use, there are ample data on the deterioration of emission levels from the cars now being driven. These data are the best available indications of the deterioration as a function of mileage that can be expected to occur with the new systems.

Between March 1968 and January 1970, EPA conducted a study (20) of the emissions from 1968-1969 model year vehicles being used in rental service. The average mileage at the time tested was 7708, the range of mileage was 30 to 27,000, and most mileages were under 15,000. In this group of 705 cars, about 25 percent exceeded the Federal HC standard and about 40 percent exceeded the CO standard. The EPA report on this project states, "Projection indicates, however, that a smaller percentage of the vehicles represented in this test program will meet certification standards when they have been operated 50,000 miles." A further finding was that HC emissions had already started to deteriorate by 3500 miles.

California has conducted surveillance testing of emissions from vehicles in use since December 1965, when the first emission-controlled cars were introduced. In general, the results of this program show that cars exceed the applicable standards before 50,000 miles, even though they comply when new. Table 14 shows average data taken from the surveillance report covering the January-March 1972 period (21). These data again show that the emissions have exceeded the applicable standards at relatively low mileages.

Atlantic Richfield (ARCO) has conducted the Clean Air Caravan and idle HC and CO emissions were measured nation-wide in 1970 (22) and in 1971 (23). Figures 16 and 17 show the idle HC and CO distribution curves for these two years for 1970 model year vehicles, which had HC or CO emissions sufficiently high to justify a carburetor adjustment. Comparison of the 1970 distribution before adjustment with the similar 1971 curve gives the deterioration in one year; e.g. the percentage of cars with HC emission less than 300 ppm dropped from about 60 percent to 40 percent during the year. The percentage with CO emissions less than 3 percent dropped from 30 percent to 15 percent. The after-adjustment curves for HC indicate that there was deterioration during the year that could not be corrected by carburetor adjustment. This is not true for the CO emissions.

Although Figures 16 and 17 show significant deterioration in one year they do not indicate how rapidly this occurs. A study done by Northrop (24) for the California ARB indicates that most of the reduction in emissions achieved by a tune-up has been lost by the end of 6 months.

EFFECTS OF FUELS AND LUBES

Catalysts in 1975-1976 emission control systems will require the use of special fuels and lubricants to minimize surface deactivation from noncombustible materials. EPA has proposed rules (25) limiting lead to 0.05 g/gal. and phosphorus to 0.01 g/gal. in at least one grade of gasoline of 91 Research Octane Number or higher beginning on 1 July 1974, i.e., in time for the introduction of the 1975-model cars. EPA has not proposed rules limiting the sulfur content of gasoline or rules limiting lubricating oil additives.

TABLE 14 CALIFORNIA AIR RESOURCES BOARD SURVEILLANCE DATA, JANUARY-MARCH, 1972

Model Year	Approx. Ave. Mileage	Ave. HC ppm Manu. A	B	C	Ave. CO % Manu. A	B	C	Ave. NO_x ppm Manu. A	B	C
I.	Standards: 7-mode cold start	275 ppm			1.50 %					
1966	64,000	405	346	376	1.99	1.67	1.80	1272	1147	1192
1967	56,000	334	418	291	1.75	1.42	1.53	1496	1110	1064
1968	50,000	317	324	298	1.82	2.04	1.68	1454	1013	1219
1969	38,000	278	339	336	1.71	1.84	1.62	1440	1197	1315
II.	Standards: 7-mode cold start	180 ppm			1.00 %			1075 ppm (1971)		
1970	32,000	262	242	224	1.59	1.31	1.10	1250	1150	1348
1971	13,000	174	205	206	1.27	0.97	1.18	871	888	1022
III.	Standards: 7-mode cold start	125 ppm			1.00 %			800 ppm		
1972	3,000	147	119	130	0.75	0.40	0.57	889	647	784

Reference: Surveillance of Motor Vehicle Emissions in California, Quarterly Progress Report No. 27, p. 15, January-March, 1972, California Air Resources Board Laboratory, Los Angeles, California

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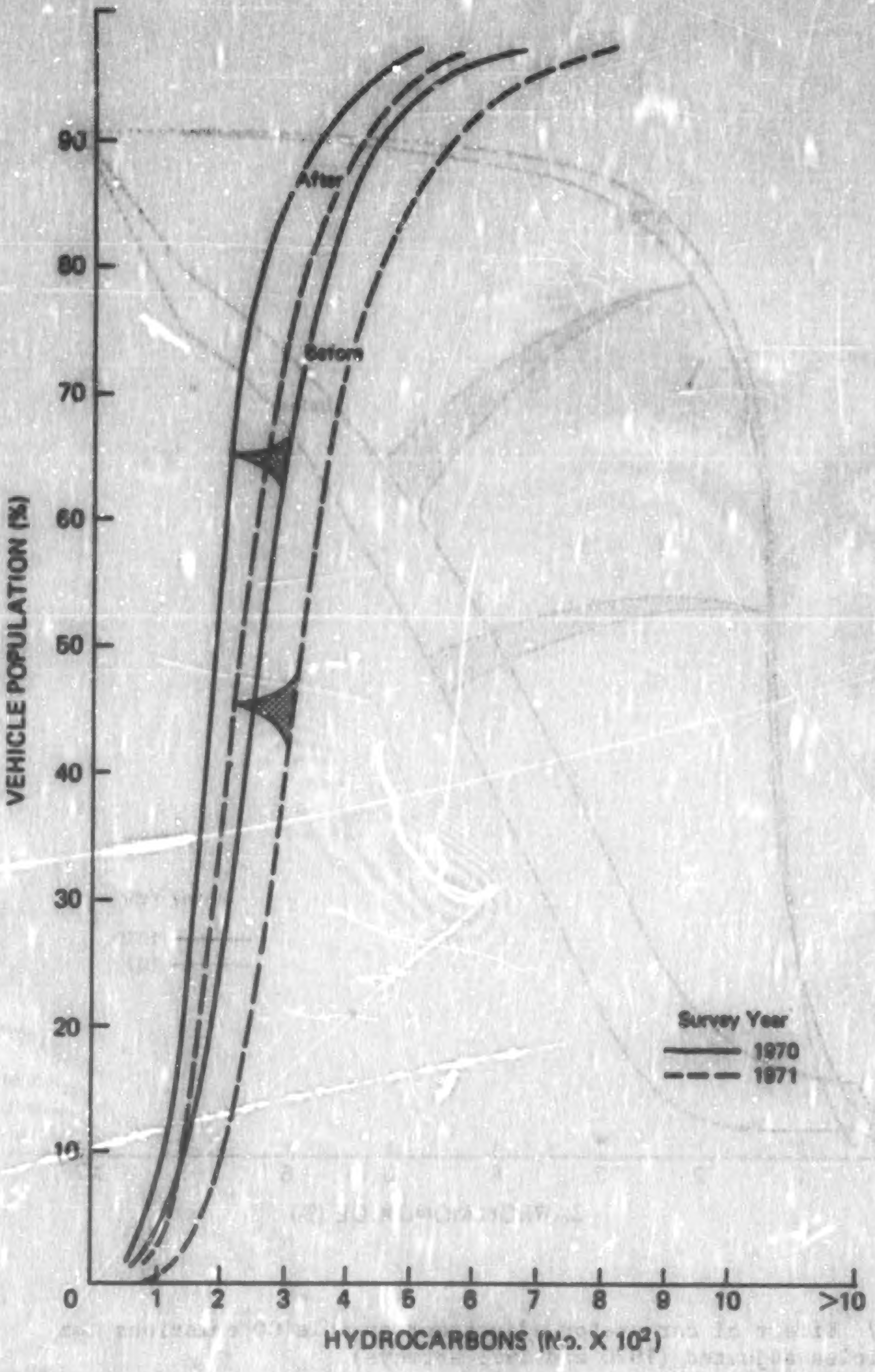

FIGURE 16 Effect of carburetor adjustments on idle HC emissions for 1970 vehicles adjusted (1970 and 1971 surveys).

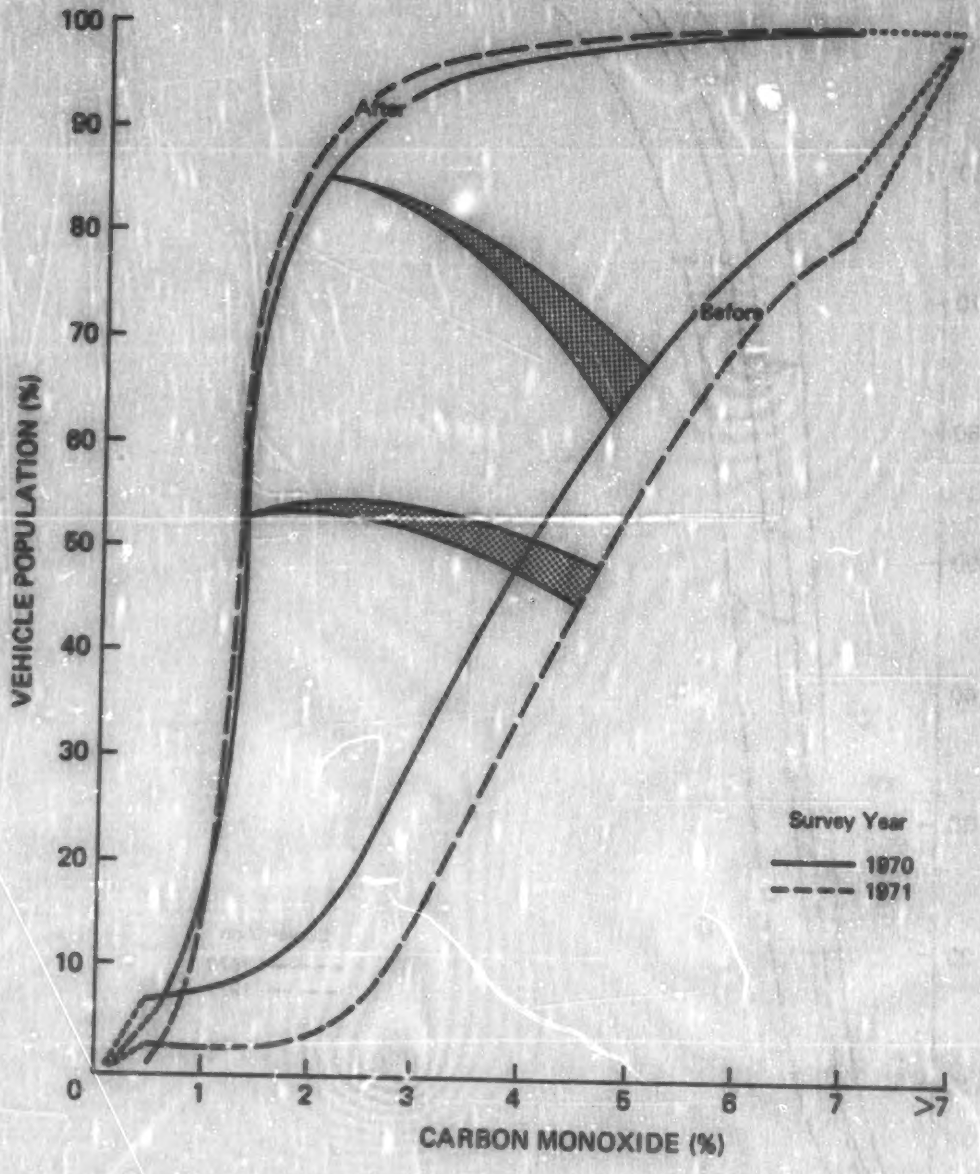

FIGURE 17 Effect of carburetor adjustment on idle CO emissions for 1970 vehicles adjusted (1970 and 1971 surveys).

The petroleum refiners feel that it may be impossible to limit one grade of gasoline to 0.05 g/gal. of lead as long as it is also necessary to market some gasoline to which lead has been added. The problem arises in the distribution, not the refining, since parts of the system must be used to distribute both leaded and nonleaded fuel. Completely separate distribution systems are not feasible before the introduction of the 1975 models, although they are technically feasible at a later date and at a high cost. The need for leaded gasoline and, with it, the need for separate distribution systems will disappear as older cars are replaced.

The catalyst suppliers (27) and the automobile manufacturers (28), on the other hand, believe they have evidence that even as little as 0.05 g/gal. of lead is a major contributor to the deterioration of catalysts. They have recommended that the maximum allowable lead content be set at 0.03 g/gal. Data on a catalytic retrofit system on an older car show that operation at higher temperatures (about 1600°F) will remove the lead from a catalyst poisoned by leaded fuel after three or four tankfuls of nonleaded fuel and will restore catalyst activity (29). This system was not achieving 1975 standards so that the data are not directly applicable although they indicate a possible solution. The planned control systems for 1975-1976 will not operate catalysts at this high a temperature so lead at the level (0.05 g/gal.) specified by EPA may remain a problem. In addition, it appears that higher lead levels will occur fairly frequently with the present distribution system.

The problems connected with the other noncombustibles do not appear as difficult to solve, although phosphorus is also reported as affecting catalyst activity and possibly catalyst support deterioration. Phosphorus is added to fuels to suppress surface ignition and lead fouling of spark plugs. Since both of these problems are associated with the presence of lead, the removal of these phosphorus additives simultaneously with the removal of lead should be no problem.

Certain carburetor detergents also contain phosphorus, and carburetor detergents will be needed to keep carburetor systems clean to achieve the precise control of air-fuel ratio required to

1. Maintain NO conversions
2. Prevent catalyst burnouts, and
3. Maintain catalyst beds at a sufficiently high temperature to resist deactivation by trace amounts of non-combustibles, such as sulfur in the fuel.

Since excellent carburetor detergents are available that do not contain phosphorus and since it is possible that detergents with trace amounts of phosphorus would not be detrimental to the catalyst, carburetor detergents should not be a problem.

Sulfur in gasoline is not as harmful as lead and phosphorus because sulfur compounds are removed from catalyst surfaces at lower temperatures (28). Current averages of most gasolines ranging from 0.01 to 0.06 percent appear to be acceptable.

Removal of the highest and lowest boiling fractions of present gasoline may be needed to

1. Help lower HC and CO emissions during cold starts, and
2. Provide better distribution of fuels to different cylinders of multicylinder engines.

These changes will also help to prevent

1. evaporation losses
2. increased HC and CO emissions from "loading up" evaporative control system vapor storage units and
3. harmful engine deposits resulting from heavy catalytically cracked gasoline fractions.

The degree of volatility changes should be balanced with increase in refining costs and with usable energy per barrel processed.

Ash detergents and extreme pressure additives, two noncombustible compounds in lubricating oils, may need to be removed or reduced in concentration. However, it should be noted that a potential catalyst poison has only about one-tenth the effect in lube oil that it would have if present in the fuel. Ash detergents are usually barium sulfonates or calcium sulfonates fortified with carbonates to add base, and they are added to provide dispersancy and antirust properties. Nonash polymeric dispersants have been developed, but the sulfonates are retained to provide antirust properities required by severe AMA tests. When lead is removed from the fuel (and, with it, the lead scavengers--ethylene dibromide and ethylene dichloride), rust in engines will be significantly reduced and the need for lubricating ash-type additives will decrease or be eliminated. Ashless-type rust inhibitors may be needed for operation in the colder climate if the basic ash-type additives are completely eliminated.

The potential need for removal or reduction of phosphorus in the lubricating oils may create a lubricating oil development problem. Zinc dithiophosphate extreme-pressure additives in combination with hardenable castiron cam shafts and valve lifters are used extensively in the automobile industry. This additive and metallurgy combination has solved many problems of scuffing, wear, and pitting of cam and lifter surfaces under extreme pressure. The search for another extreme pressure(EP) additive for this difficult boundary lubrication problem will involve many compromises between EP activity, corrosion and rust of engine parts, excessive corrosive attack (wear or pitting) of the cam and lifter surfaces, effect on catalyst life, and others. Data on a catalytic converter retrofit system on an older car showed that very high consumption rates of a conventional ash-type oil (50 to 150 miles per quart) did not deactivate the catalyst (29). This system did not meet 1975 HC and CO standards; therefore, these data are not directly applicable to the performance of 1975-1976 emission control systems. At low or normal oil consumption rates, ash and phosphorus may cause a gradual decrease in activity of these low emission systems.

In summary, the lead content of gasoline will remain a factor affecting the feasibility of meeting the standards in actual use. The phosphorus content of lube oils may present a problem. The other fuel and lube problems do not appear to be serious.

ADEQUACY OF THE SERVICE INDUSTRY

The service industry at the present time is not adequate to service the 1975-1976 cars from an emission-control standpoint. All three aspects are inadequate: knowledge of the devices, equipment with which to diagnose for malfunctions, and the number of mechanics. The number of vehicles per mechanic in the country rose from 75 in 1950 to 145 in 1970 (30), despite the fact that cars became more complex and less repair-oriented in design. The states that have studied the problem all feel that training on emission control devices is needed and that the states should at least recommend suitable equipment. New York plans to certify garages as properly equipped for emission control work. California licenses the adequately trained mechanics, and New Jersey will depend on the promise of large-volume business to motivate the private sector to establish their own training and licensing programs. The service industry mechanic must be trained to understand and perform repairs and adjustments, and this must be done regardless of whether or not he performs the complete or partial diagnosis to isolate problems causing excessive emissions. The amount of training will vary slightly with the degree of state control on mechanics but will generally be extensive. The task of developing a sufficient number of qualified mechanics to maintain complicated 1975-1976 emission control systems within the time constraints may not be feasible.

Number of Mechanics

The number of mechanics required to maintain 1975-1976 emission control systems will depend on the interpretation of the 50,000-mile warranty provision of the Act. If the new car dealerships assume the responsibility and owners are required to bring their cars into the dealers' garages for periodic inspection and maintenance, a new force of about 12,000 men per year will need to be trained for the dealers, on the assumption that 1975-1976 control systems will require about two hours more per year than is now spent to perform routine inspection and maintenance. This number of men will need to be added each year for about five years, if new car dealers maintain new cars during warranties; i.e., a new work force of about 60,000 men will be needed by 1980. At the time when warranties expire, experience has shown that most owners will take their cars to garages other than new car dealers; hence, after 1980, a large indefinite number of mechanics in garages other than dealerships will need to be trained. The number of mechanics in the general service industry is difficult to estimate because most of them will probably work only part time on emission control.

Training

Most mechanics are sufficiently skilled at performing repairs and parts replacements but lack the knowledge of completing a diagnosis of problems related to excessive emissions. Table 15 gives opinions on the capability of present mechanics to both diagnose and repair the listed malfunctions without further training, expressed by three organizations that responded to the questionnaire on deterioration and maintenance. The percentages given by Scott average about 65 percent, those by American Motors about 50 percent, and those by Rice and Holman about 48 percent. Table 15 should not be interpreted to mean that there is only a 50 percent chance of proper repair in an American Motors dealership; work in these shops is done on a specialty basis and the numbers quoted are averages across all mechanics. A specific test of the ability of mechanics to diagnose and repair malfunctions that had been purposely introduced gave results that agree quite well with these estimates. Although there was considerable spread in the results from different shops in this study, the generally low percentage of correct diagnoses and repairs on the project is certainly significant since the mechanics knew that something was out of adjustment, even though they did not know what.

TABLE 15 CAPABILITY OF MECHANICS TO DIAGNOSE AND REPAIR MALFUNCTIONS

System Parameter	Percent Present Mechanics Capable		
	Scott	Rice and Holman	Amer. Mts.
Carburetion			
A/F at idle	50	30	50
A/F main jet	40	30	40
A/F power jet	--	30	40
Choke	10	30	50
Heat riser valve	90	--	50
Altitude compensation	--	--	--
Leaks intake manifold	60	80	40
Leaks vacuum line	70	55	40
Air Cleaner--plugged	70	100	50
Ignition			
Misfire--plugs	80	50	50
Misfire--wiring	70	50	40
Misfire--cap and rotor	70	50	40
Basic timing	70	40	85
Automatic spark advance	60	10	40
Devices			
PCV system	80	90	50
EGR system	70	--	10
Air pump system	60	--	40
Oxidation catalyst	--	--	0
Reduction catalyst	--	--	0
Overtemperature protection	--	--	30
Evaporative control system	70	90	90
Other			
Idle speed	90	40	65
Burned exhaust valve	80	50	65
Low compression	80	50	65

California is the only state that licenses mechanics to install and repair emission control devices. Only a few states have plans to license mechanics. A 40-hour training course has been used to teach the licensed California mechanics:

1. The fundamental relationship between engine operating parameters and exhaust emissions,
2. Diagnostic techniques with HC and CO meters, and
3. Cost-effective repairs.

Training will also be needed for the performance of specific functional tests on 1975-1976 control systems.

New Jersey has also found that more than a simple indoctrination of mechanics is needed in order to obtain cost-effective emission tune-ups.

Equipment

The garages in the service industry will need to be significantly upgraded with new equipment to perform diagnoses and tests to determine if vehicles need adjustment or repair and to show that the adjustments and repairs were accomplished. The amount of equipment needed will depend on whether or not the state operates inspection stations and what kind of inspection test the state performs. However, the state would need to perform the complete diagnosis and instruct mechanics on what parts to replace in order to reduce significantly service industry equipment requirements.

A list of major equipment and test instruments required by the service industry to diagnose, repair, adjust, and inspect emission controls follows:

1. HC and CO infrared meter or equivalent
2. Ignition analyzer with an oscilloscope
3. Ignition analyzer or alternative equipment for determining if the NO control is functioning

4. Apparatus and gases for calibrating HC, CO, and NO meters
Most garages probably have ignition analyzers. Items 1 and 4 together will cost $2,000 to $2,500.

ADEQUACY OF PARTS SUPPLY

The $13 billion parts sales in 1971 represented a 15 percent increase over 1970 but the average growth rate is probably closer to 10 percent per year. The emission-related parts costs of $76 per car per year for 1975 and $86 for 1976 represent about a 60 percent increase in parts sales that would be phased in over a 10-year period for an increase of 6 percent per year. It appears that this additional growth could be handled by the parts industry without serious difficulty.

Another point with respect to the parts industry is the quality of replacement parts. There are parts such as solenoid switches that either work or do not, and after-market suppliers would probably provide an acceptable product. Unfortunately, there are other items like the new carburetors that require very precise specifications to achieve the emission limits and replacement parts must be identical. At present, many rebuilt carburetors and other replacement carburetors reach the market with compromised specifications so that they can be used on several car models and emissions where these have been used have been unsatisfactory. Control of the replacement of critical components appears to be a difficult problem. The Federal government could attempt to control parts manufacturers under the interstate commerce powers and the states could make the possession or sale of non approved parts illegal. But what is a non approved part? A replacement part with specifications compromised so that it can be used on several cars may be almost ideal for some cars and unsuitable for others. Hence, its presence on the shelf is not illegal. There is the business incentive of low inventory to stock such parts. States could, of course, prohibit the installation of non approved parts and this could be policed by periodic or spot inspection. However, it appears that the percentage of incorrect parts in use will average high enough to have a significant impact on emissions.

THE EFFECT OF UNTREATED EXHAUST

A 1975-1976 car with one or more of the critical control devices not operating will emit many times the pollutants emitted by a properly operating vehicle. Similarly, the leakage of a small percent of untreated exhaust will equal in pollutant effect the entire exhaust from a properly operating car. It is possible to calculate the percent of untreated exhaust that will cause the average emissions to exceed the allowed standards. It is immaterial whether this untreated exhaust comes from a few cars with failed control devices or from the cars, in general, through leakage.

This calculation has been made and is described in Appendix D. Estimates of the pollutants in untreated exhaust were obtained from the manufacturers by requesting them to estimate the emissions from the 1975-1976 cars if specified control devices failed. The car population was assumed to be uniformly distributed in mileage from zero to 50,000 (the legal useful life), the new cars were assumed to be emitting only one-half the standards at zero miles, the deterioration of the average car was assumed to be linear with mileage, and the average car was assumed to be emitting just the standards at 50,000 miles. On these assumptions, the amounts of untreated exhaust (number of failed devices) that would cause the average emissions from the entire population (zero to 50,000 miles) to just equal the standards are shown in Table 16 as a percent of the total.

TABLE 16

Pollutant	Percent Untreated
CO	2.2
HC	3.7
NO_x (treated by EGR only)	7.7
NO_x	2.7

It should be noted that the requirement that the average emissions from the entire population, distributed in mileage from zero to 50,000, meet the standards is a different and less stringent requirement than that the average emissions from a class of vehicles remain at or below the standards for 50,000 miles. It is the latter requirement that was developed by the Panel (see Introduction, paragraph 1) as the least restrictive, practical interpretation of the law. With the assumed population of vehicles, any untreated exhaust, no matter how small, would cause the standards to be violated on the basis of the definition of meeting the standards in actual use, which is given in the Introduction. Consequently, the values in Table 16 should be taken only as indications of how sensitive compliance with the standards is to small amounts of untreated exhaust.

Table 17 presents the same data in other units; namely, by what factors would the average emissions from the entire population (note above explanation) exceed the standards if there were 5 percent and 10 percent untreated exhaust. Separate values are given for each pollutant.

TABLE 17

Pollutant	Emission as Fraction of Standards	
	5% Untreated	10% Untreated
CO	1.3	1.9
HC	1.1	1.4
NO_x (treated by EGR only)	0.9	1.1
NO_x	1.2	1.7

There are no firm data on the amount of leakage or on the failure rates of critical components to be expected. However, the Panel on Catalysts was told by GM on 6 June 1972, "GM has seen many monolith failures," and by Ford on 8 June, "Many massive failures of monoliths were observed." During these same visits Chrysler, Ford, and GM all expressed concern over the problem of protecting catalysts from overtemperature. Ford and GM both mentioned difficulty with leakage through a bypass valve, and Ford said they had not been able to reduce leakage below 5 percent. This Panel was told that over 5 percent of all the catalytic converters tested by Ford had had catastrophic overtemperature failures; this statement was made on 27 April 1972, so it may not represent the latest results.

If an extrapolation of known failure rates of present components is added to the observations quoted above, the result is a fairly definite indication that the untreated exhaust from cars in the hands of the public will be 5 percent or more.

PROBLEMS CONNECTED WITH ENFORCING PROPER MAINTENANCE

The Panel is unanimous in believing that mandatory maintenance is necessary to obtain the potential emission reductions from the 1975-1976 cars, regardless of whether these vehicles meet the standards in actual use. There is no requirement in the Act that the owner maintain his car. There is, however, provision for grants to states for developing and maintaining emission control programs (Section 210). Section 207 grants the EPA Administrator the authority to establish methods and procedures "to ascertain whether, when in actual use throughout its useful life, each vehicle and engine to which regulations under Section 202 apply complies with the emission standards of such regulations." If he exercises this authority, and if failure to meet the standards makes the owner liable to any penalty or sanction under Federal or State law, the manufacturer must correct the nonconformity at his expense (individual car-warranty provision).

It was noted previously that testing, inspection, and maintenance is simply control by another name and it was also noted that the primary objective of the Act was to reduce the vehicle contribution to the pollutant burden. Control of the vehicle contribution to air pollution can be accomplished by controlling the emissions from the average car. It can also be accomplished by insisting that each car meet specified standards. Enforcing the individual car warranty requires this latter method.

Both of these approaches to controlling the vehicle contribution to air pollution are interwoven with methods of enforcing proper maintenance. The Act indicates that the development and management of a system of mandatory maintenance is a State responsibility, even though the Federal government can prescribe the method to be used if enforcing the warranty provision is part of the system.

Comparison of the Sequence Steps Resulting From the Two Control Philosophies

Whether just the emissions from the average car or the emissions from every car are controlled makes a significant difference in the steps included in the testing sequence from prototype to mechanic. Which control philosophy is followed may depend on whether the decision is made to enforce the individual car warranty. The wording of the Act appears to allow discretion in this regard and the states have the option of not attaching any penalty or sanction to failure to meet specified standards.

Figure 18 depicts a sequence based on the philosophy of controlling just the average emissions whereas Figure 19 depicts a sequence based on the philosophy that every car must meet appropriate standards. As indicated in the figures, the first sequence is quite simple and the decisions required at various points are straightforward, while the second sequence is complicated to the point where there does not appear to be a logical answer at some decision points. These two sequences are probably the extremes; the second sequence adheres strictly to the philosophy that every car must meet standards, including every car at the time of production and every car in use both from an emission reduction standpoint and a warranty standpoint. The figures do not attempt to include the various choices at the points where more than one method is available, e.g., inspection/maintenance methods.

There are no difficult decision points in the sequence (Figure 18) designed only to accomplish the basic objective, reducing air pol-

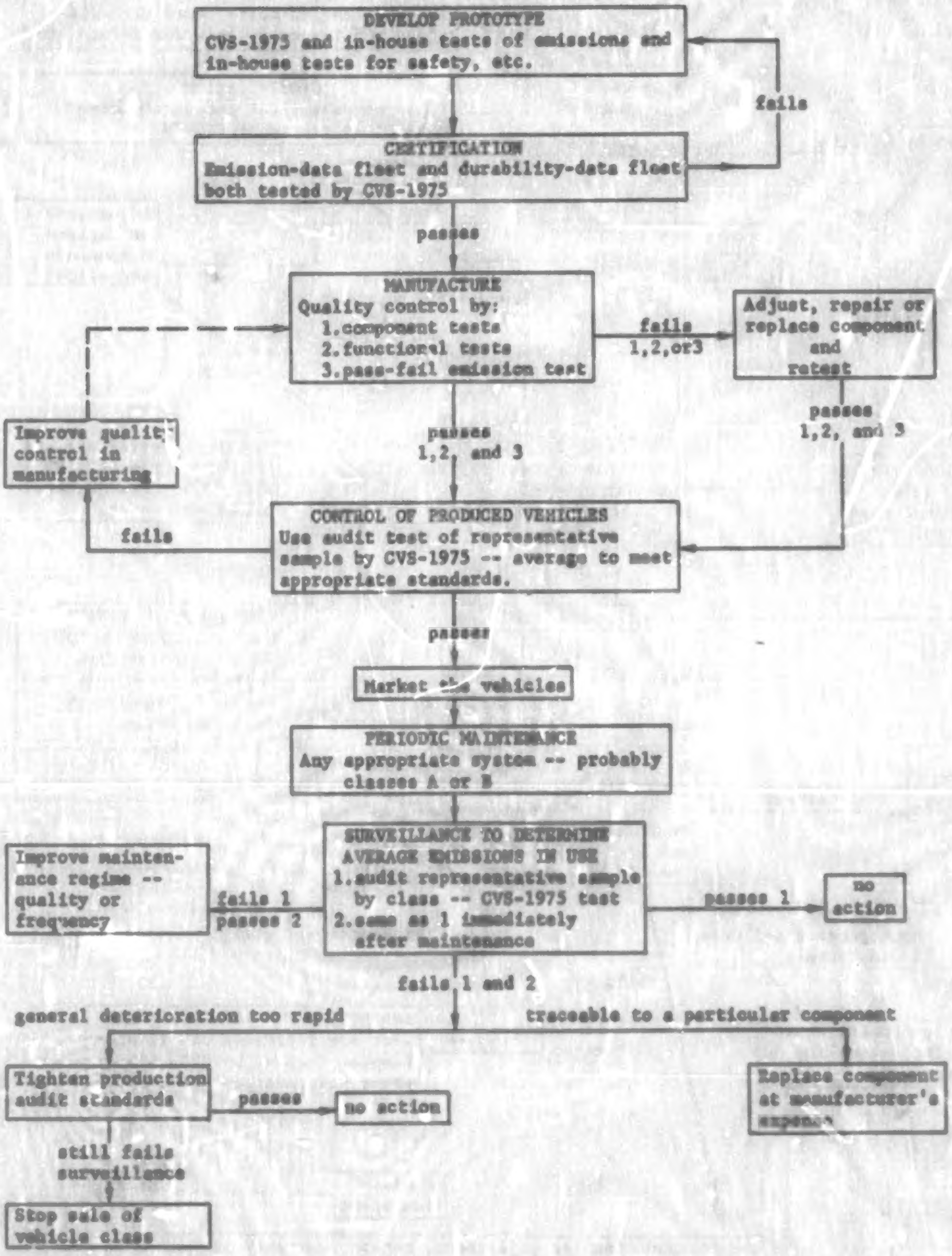
DEVELOP PROTOTYPE
CVS-1975 and in-house tests of emissions and in-house tests for safety, etc.
fails
CERTIFICATION
Emission-data fleet and durability-data fleet both tested by CVS-1975
passes
MANUFACTURE
Quality control by:
1.component tests
2.functional tests
3.pass-fail emission test
fails 1,2,or3
Adjust, repair or replace component and retest
passes 1,2, and 3
passes 1,2, and 3
Improve quality control in manufacturing
fails
CONTROL OF PRODUCED VEHICLES
Use audit test of representative sample by CVS-1975 -- average to meet appropriate standards.
passes
Market the vehicles
PERIODIC MAINTENANCE
Any appropriate system -- probably classes A or B
SURVEILLANCE TO DETERMINE AVERAGE EMISSIONS IN USE
1.audit representative sample by class -- CVS-1975 test
2.same as 1 immediately after maintenance
Improve maintenance regime -- quality or frequency
fails 1
passes 2
passes 1
no action
fails 1 and 2
general deterioration too rapid
traceable to a particular component
Tighten production audit standards
passes
no action
Replace component at manufacturer's expense
still fails surveillance
Stop sale of vehicle class

FIGURE 18 Steps in a simple testing sequence.

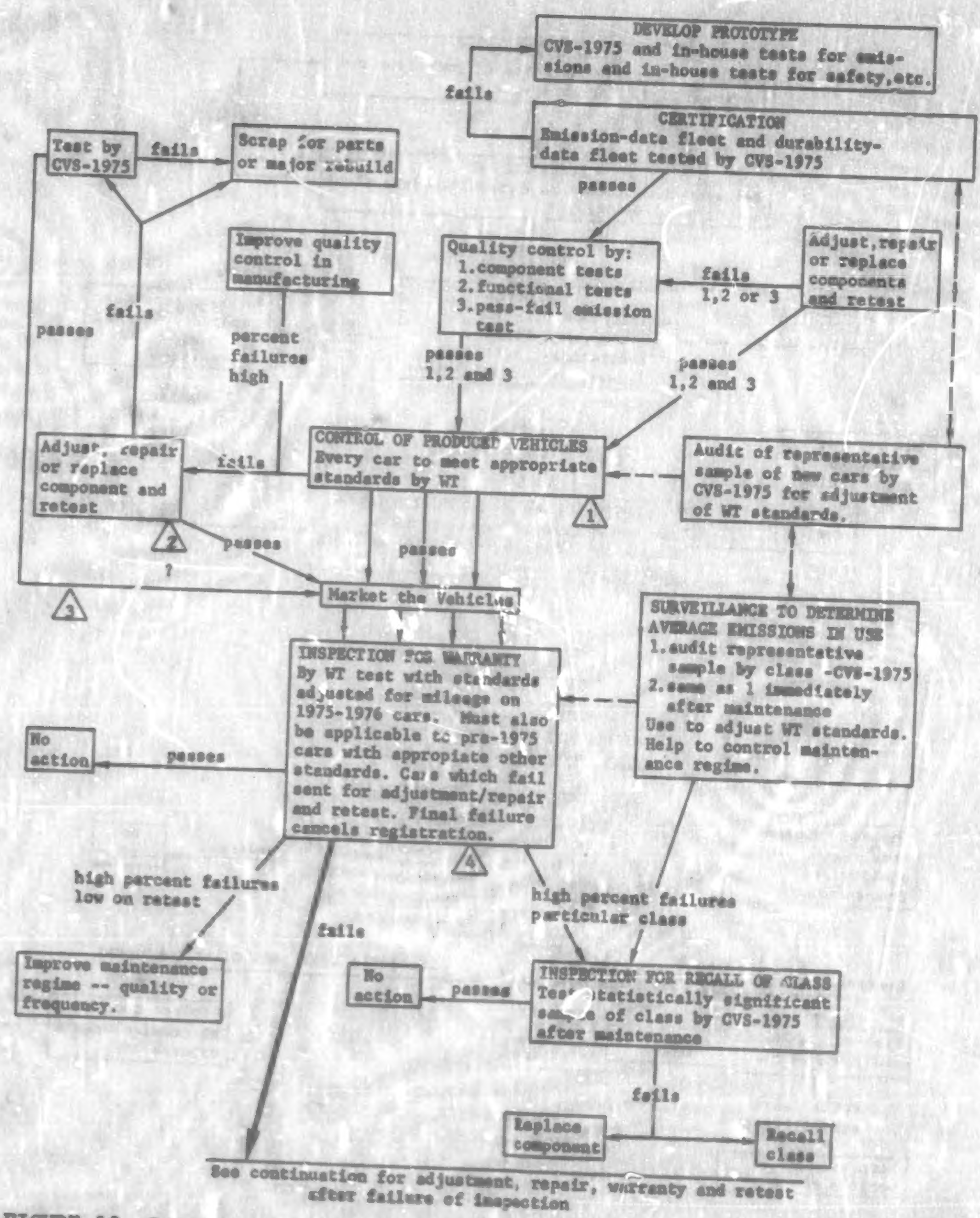
DEVELOP PROTOTYPE
CVS-1975 and in-house tests for emissions and in-house tests for safety,etc.
fails
CERTIFICATION
Emission-data fleet and durability-data fleet tested by CVS-1975
passes
Test by CVS-1975
fails
Scrap for parts or major rebuild
Improve quality control in manufacturing
Quality control by:
1.component tests
2.functional tests
3.pass-fail emission test
fails 1,2 or 3
Adjust,repair or replace components and retest
passes
fails
percent failures high
passes 1,2 and 3
passes 1,2 and 3
Adjust, repair or replace component and retest
fails
CONTROL OF PRODUCED VEHICLES
Every car to meet appropriate standards by WT
1
Audit of representative sample of new cars by CVS-1975 for adjustment of WT standards.
2
passes
passes
?
3
Market the Vehicles
SURVEILLANCE TO DETERMINE AVERAGE EMISSIONS IN USE
1.audit representative sample by class -CVS-1975
2.same as 1 immediately after maintenance
Use to adjust WT standards. Help to control maintenance regime.
INSPECTION FOR WARRANTY
By WT test with standards adjusted for mileage on 1975-1976 cars. Must also be applicable to pre-1975 cars with appropiate other standards. Cars which fail sent for adjustment/repair and retest. Final failure cancels registration.
No action
passes
4
high percent failures low on retest
fails
high percent failures particular class
Improve maintenance regime -- quality or frequency.
No action
passes
INSPECTION FOR RECALL OF CLASS
Test statistically significant sample of class by CVS-1975 after maintenance
fails
Replace component
Recall class
See continuation for adjustment, repair, warranty and retest after failure of inspection

FIGURE 19 Steps in a testing sequence designed to enforce individual car warranty.

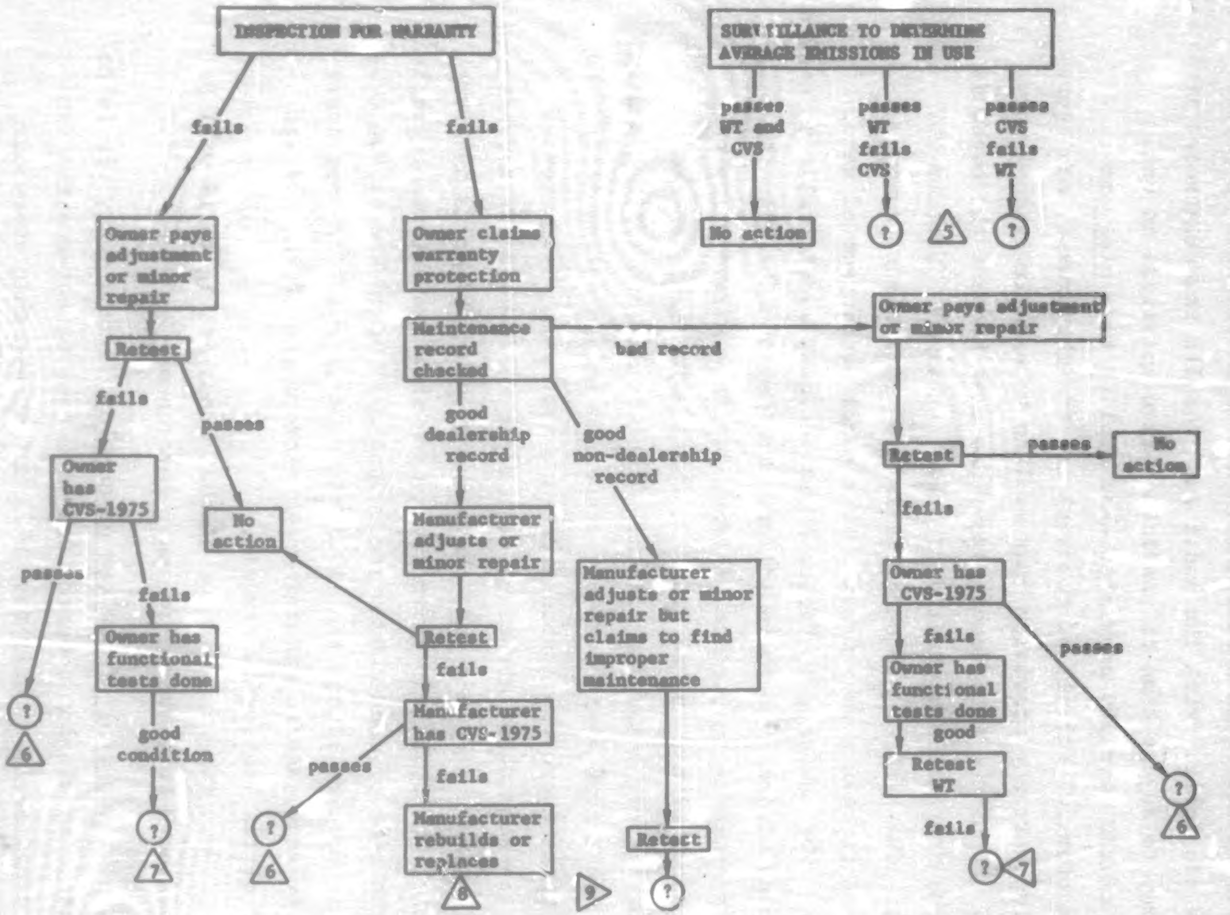
INSPECTION FOR WARRANTY
fails
fails
Owner pays adjustment or minor repair
Retest
fails
passes
Owner has CVS-1975
No action
passes
fails
Owner has functional tests done
good condition
Owner claims warranty protection
Maintenance record checked
bad record
good dealership record
good non-dealership record
Manufacturer adjusts or minor repair
Retest
fails
Manufacturer has CVS-1975
passes
fails
Manufacturer rebuilds or replaces
Manufacturer adjusts or minor repair but claims to find improper maintenance
Retest
SURVEILLANCE TO DETERMINE AVERAGE EMISSIONS IN USE
passes WT and CVS
passes WT fails CVS
passes CVS fails WT
No action
Owner pays adjustment or minor repair
Retest
passes
No action
fails
Owner has CVS-1975
fails
passes
Owner has functional tests done
good
Retest WT
fails
?
5
6
7
8
9

FIGURE 19 (concluded) Steps in a testing sequence designed to enforce individual car warranty.

lution (average emissions), since all of the decisions can be based on the official CVS-1975 test. Even the selection of appropriate standards for the CVS-1975 test audit of new cars would be comparatively easy since CVS-1975 results from certification and from surveillance in use will both be available. With the audit test results thus bracketed it should be easy to adjust them to predict average emissions in use. Enforcement of the warranty provision that applies to a *class* of vehicles (Section 207 (c) (1) of the Act) is straightforward, as Figure 18 shows. The warranty provision that applies to each individual car (Section 207 (b) of the Act) never comes into play because the owner is never required "to bear any penalty or other sanction" (Section 207 (b) (2) (C)). The periodic maintenance is used to minimize average emissions, not to refuse registration to a small percentage of cars.

The sequence in Figure 19 is designed specifically to enforce the warranty provision on each individual car (Section 207(b)). On this basis, a periodic inspection of every car is done and every car must be adjusted, either by the owner or the manufacturer, to meet standards, or the car cannot be driven. Since it seems illogical and illegal to demand that every car meet standards in use unless it is known that it met appropriate standards when new, each car is tested when new by the same short hot-start test later to be used for warranty. Section 207(b) makes it clear that the warranty of each car is in terms of the official CVS-1975 test so it is assumed that a statistical sample of cars at the time of manufacture and in use will be tested by the CVS-1975 procedure both to adjust the standards used in the short hot-start test (warranty test) and to determine the performance of the average car in terms of the legal requirements.

Only the difficult or unusual steps in Figure 19 will be discussed and they are numbered for easy reference:

1. *Control of new car production*. Since every car is to be tested, the time element requires that the test be hot-start. For reasons discussed earlier, this test will not ensure that every car meets the selected standards and it will not pass and fail the same cars as the CVS-1975 test. Improving the reproducibility of the test will just reduce the *percentage* of cars which are either passed or

failed incorrectly, but reducing the *number*, passed or failed incorrectly, to insignificance is a practical impossibility when the annual production is 10^7 units. With regard to the two tests not passing and failing the same vehicles, the correlation coefficient is irrelevant unless it is 1.0. Even at this impossible point the CVS-1975 and the short-hot-start tests would not pass and fail the same cars because of the lack of repeatability in both tests.

As a result of the above, the cars passed by the short test include the following: (a) cars that would pass both the short and CVS tests on repeated testing, (b) cars that would pass the short test and fail the CVS, and (c) cars that would fail the short test on repeated testing (might either pass or fail the CVS). These are not all the combinations but they illustrate the complexity (shown by multiple arrows) and foretell the complexity to be encountered in enforcing the individual car warranty. The ones failed by short or warranty test (designated WT) contain similar combinations.

If the control of new production is solely on the basis of every car passing the WT, there is no real control on the average emissions and this can be brought closer and closer to the maximum by better quality control. As discussed previously, a requirement that the average meet some standard avoids this difficulty whether the test is the CVS or the WT. The audit by the CVS at this point presents no particular problems since it is intended only for surveillance and for adjustment of the WT standards even though there will be disagreements between it and the WT on individual cars.

2. *Adjustment of failed cars*. Since the requirement is to pass the WT, cars which fail will, if possible, be adjusted to pass this test. This is in reality a requirement that the manufacturers develop cars to pass the CVS and build them to pass the WT. In doing this adjustment, some cars that would pass the CVS will be adjusted to pass the WT and fail the CVS.

3. *Pass the CVS--fail the WT*. After original failure and subsequent adjustment, some cars will continue to fail the WT. Rather than scrap these vehicles for parts (install new engine and controls)

the manufacturer may choose to test them by the CVS. It would seem that the manufacturer is legally entitled to sell the ones that pass with appropriate allowance for deterioration, etc. Actually these cars are more strictly in compliance than the ones that just pass the WT. When these cars are sold, however, another category has entered the group later to be tested for compliance in use. It is a troublesome category, because these cars would never pass the WT even though they passed the CVS.

4. Inspection for warranty. This is done by the same test used for production control (WT) and cars that cannot be adjusted/repaired to meet the standards cannot be driven. This is the state sanction that invokes the warranty provision (Section 207(b)(2)(C) of the Act). A difficulty here is the setting of standards; different ones must certainly be used on the basis of vehicle mileage, since a car nearing 50,000 miles cannot reasonably be expected to meet the same standards as a 10,000-mile vehicle.

5. Surveillance by the CVS. Surveillance by the CVS to audit the average emissions in use and to control the adjustment of the inspection standards will identify two groups of cars, the handling of which may require special decisions. These are the ones that pass the WT and fail the CVS and the ones that fail the WT and pass the CVS. It appears not only unfair but also illegal to deny an owner the right to drive a vehicle that satisfies the requirements of the Act even if it fails the WT. This logical trap arises at several places in the complex system.

6. Passes CVS--fails WT. There are at least three points in the system where this situation can easily arise. Denying the owner the right to drive his car under these circumstances appears to be legally unenforceable as well as unfair.

7. Fails both WT and CVS but in good condition. The situation where a relatively new car fails both the WT and CVS, but competent mechanics can find no component outside of specifications poses another problem both ethically and legally. The Act does not state that an owner must follow the manufacturer's prescribed maintenance.

If he has maintained the vehicle so that it is in good condition, requiring him to make major replacements of good components before he can drive the car seems both unfair and unenforceable. This is particularly true since he may have purchased one of the cars that never met the standards.

8. Fails both WT and CVS with prescribed maintenance. This is the only situation under the Act where the manufacturer can be required to repair or replace a vehicle and then, perhaps, only if the argument under Item 7 is not invoked. This may have a tendency to channel more and more of the maintenance work into the dealerships at the expense of the independent garages (see Item 9).

9. "Improper" maintenance by independent garage. When a manufacturer adjusts a car that has been maintained by an independent garage, he can claim that he found signs of "improper" maintenance. The question of his liability under the warranty provisions of the Act would then have to be settled in the courts.

At first glance it would appear that some intermediate sequence could be designed to give more control over individual cars than the simple sequence and still avoid the logical traps of the complete sequence. This is not easy to do and, in fact, appears to be impossible if an emissions test of every car is used to determine whether the car can be legally driven and to enforce the warranty. In general the same conflicts will arise. A simpler sequence that appears to satisfy the requirement of the Act on the warranty of each individual car and that avoids the complications diagrammed in Figure 19 is the following: The control of new cars would be by the CVS test in an audit procedure, as in Figure 18, and the Administrator would rule that the warranty would be based on functional tests that determined whether the components were continuing to operate inside of specifications. This still leaves a conflict with a state requirement to pass an emissions test if the penalty for not passing is denial of the right to drive the vehicle within the state. The other complication in this system is that such functional tests would be quite time-consuming compared with a short emissions test and, consequently, would require a significant increase in the number of inspection facilities and trained personnel.

Effect of Federal Action

The large impact of Federal law on the total system has been discussed above. Certain Federal action or lack thereof has had a noticeable effect on state action in the field. The Act preempted the field of motor vehicle emission control for the Federal government. This raised several problems connected with the design of state systems. The first is a tendency toward delay; in the few cases where a state had already started the design, revision was necessary and the states that had not started tended to wait for Federal action. This tendency to wait is occasioned by the fact that the EPA has not activated certain provisions of the law and has not indicated their course of action, if any.

It has been noted that the Act requires EPA to promote state inspection and maintenance and that the warranty of individual vehicles is interrelated with the decision on testing of new vehicles at the end of the assembly line. Until these decisions are announced by EPA, the tendency is for the states to delay. Federal funds were also to be available to assist states in implementing inspection/maintenance programs. It appears that EPA is discouraging state action at this time by not furnishing such funds in order to minimize the establishment of tests and methods other than the one EPA will specify.

Time Required for Instituting Maintenance System

State interest in inspection and maintenance of motor vehicles as a means of reducing exhaust emissions is much older than would be surmised from the fact that no statewide system of inspection coupled with mandatory maintenance was in operation in any state on 1 July 1972. The New Jersey (31) investigation which has led to their system, put in operation on 5 July 1972, started in 1966. It should be noted that even in the New Jersey system, which is the farthest advanced, the feature of mandatory maintenance will not be instituted until 5 July 1973. The first year of inspections will be used only to educate the public and eliminate the difficulties. New York has had a law specifying exhaust emission standards for any car registered in the state since 15 June 1967. California has required a certificate of compliance from licensed installation stations since PCV valves were first required in 1963. Idle exhaust measurement for HC and CO is also now done as part of California's roadside safety inspection. Cars exceeding certain limits must be taken to a licensed mechanic for adjustment and a notice that the work was done must be returned by mail. In summary, the development efforts over the last seven years have produced only one inspection/maintenance system (California) that is reducing exhaust emissions.

It should be possible to shorten this time, if an adequate service industry were in existence--an assumption inherent in each of the three cases discussed below. Two of the cases assume that emissions testing is done in state inspection lanes, with maintenance done elsewhere, and the third assumes that the complete mandatory maintenance is done in privately-owned facilities. The cases are

1. Safety inspection lanes are available and emissions testing can be added.

2. Properly-controlled privately-owned service facilities are available for complete mandatory maintenance.

3. Inspection lanes must be built.

New Jersey is an example of the first situation and it has proved relatively easy from a physical standpoint to add emissions testing to the state-owned safety inspection lanes. For the idle test that is used, equipment costs are about $2,000 per lane. On the assumption that legislative authority already exists, it should be possible to put emissions testing in operation in one year under these conditions. Extra manpower required would be one per lane. No meaningful estimate of operating or capital costs chargeable to the emissions testing is possible because of shared costs. Time and cost would both increase if the testing were also intended to enforce the Federal individual car warranty.

California could be an example of the second situation, since it licenses Grade A mechanics for various specialties including emission control devices. The time required in this case should also not exceed one year. Costs for added equipment would again be about $2,000 per station for an idle test. Inspection costs would be mixed with adjustment and repair costs and, consequently, a separate estimate is probably of questionable meaning.

The third situation has been studied (24,32), and one study was in considerable detail. Conditions assumed in this study (24) give a good indication of the range of costs to be expected. The land, structure, and equipment will cost from $23,000 to $60,000 per inspection lane. These numbers are approximately confirmed by another study that estimated $44,000 to $52,000 per lane for dynamometer-equipped facilities. Different tests not only use different equipment but they also have different throughputs per lane, i.e., different numbers of lanes per 10^6 cars. If both factors are considered, the cost of land, structure, and equipment on a one-inspection-per-year basis is between $1.3 and $8.8 per car when calculated for California's population distribution and 10^7 cars.

Operating costs in 1976 would be between $1.20 and $4.00 per car per year, also under California conditions. The original capital costs are a small fraction of this and are included in the above figures, with structures amortized over 20 years and equipment over 5 to 10 years. Training time for personnel would be between 90 and 180 hours per man, which includes 40 hours of classroom training and the remainder on the job. Again on the assumption that legislative authority already existed, it would probably take 1.5 to 2 years to acquire land, to erect and equip the buildings, and to train personnel.

About one year must be added to any of the above time schedules if legislative authority does not already exist. Even more time must be added if an operational plan does not exist; witness the New Jersey and New York experiences. In summary, a state starting from scratch would probably be fortunate to have a fully operational maintenance system in four years.

Socio-Economic Impact

Here are the icebergs on which the inspection/maintenance programs are foundering. The result is not to force the abandonment of the plan but rather to force acceptance of compromises that make the plan ineffectual in terms of the real objective, namely, the improvement of air quality. The problems appear to be threefold. First, the public is not ready to accept an inspection-maintenance program at a realistic cost. They answer polls in favor of a program in the abstract, but they express disapproval when realistic costs are quoted. In the Northrop study, 76 percent voted for the idea of mandatory inspection/maintenance, but when asked if they approved on the basis of a realistic cost only 33 percent voted yes.

Second, there is political opposition to any rapid change, and the politician who does not want to spend money or who wants to protect his supporters can always point to the fact that a mandatory maintenance program falls most heavily on those least able to pay, namely, the driver of the old "klunk," which is likely to be a high emitter and which can probably not be adjusted or repaired at reasonable cost. Finally, there is the enforcement question. Most of the states have made it illegal to disconnect an emission control device, but in many it is not illegal to change engine adjustment and in some it is illegal for a mechanic to tamper with a device but not for the owner.

There will probably be the incentive of better performance to entice the owner to readjust or disconnect some 1975-1976 devices. Widely-read magazines have commented on the safety hazards associated with the driveability problems created by emission control devices.

With this background the owner takes little risk in tampering with the devices, and bootlegging of "fixes" is already a common practice.

New Jersey's Experience

New Jersey's experience is the ideal example of the problems encountered by a state attempting to institute an inspection/maintenance system for the purpose of improving air quality. Their development program is the oldest, they will start 100 percent inspection the soonest, and they have experienced most of the difficulties and problems.

New Jersey has had 100 percent safety inspections since 1938. Even this program has been subjected to public criticism (33); the question has been raised that some of the 8.5 x 10^6 dollars would be better spent on driver education and the prevention of alcoholism. Each new political administration takes a new look. Registered cars in New Jersey total 3.5 x 10^6, but annual throughput is 5.5 x 10^6 since people come through more than once voluntarily, failed cars must be reinspected and some out-of-state cars use the service.

In 1966 New Jersey (31) decided that emissions inspection was needed and they instituted a program to develop a procedure and pass-fail standards. Several tests were studied in an attempt to find a test that would "correlate" with the 7-mode and could be done in 1.5 minutes or less. The ACID cycle was developed, and this was carried to the second and third generations and is now fully ready for use (33). However, when it was put into an inspection lane the public was not ready to accept it and the service industry was not ready for the load (33). At this point they realized "technical development of the test was easy compared to getting public acceptance and upgrading the mechanics". (33)

At this point they opted for a simple test to introduce the program and chose the idle test. Idle testing was investigated quite thoroughly, including some pilot testing in different parts of the state and evaluating commercially-available equipment that could handle

260 cars per day in all kinds of weather. On the basis of this study public hearings were held (34) on what was considered to be a gentle introductory program. Emission standards were projected that would send for repair/adjustment 10 percent the first year, 20 percent the second, and 30 percent the third. These had been cut back from the 30 to 40 percent they would have liked for air-quality improvement because of the political climate, lack of public acceptance, and the inadequacy of the service industry.

At the public hearing it became evident that there was considerable opposition, mainly from the sociological rather than technical viewpoint (33). The service industry was not ready and the public was nervous. Everyone became involved: labor, consumers, and industry groups. Great emphasis was put on the fact that those least able to pay would be hit the hardest. At the end, a conference was held in the governor's office and the decision was made for a further retreat to the schedule listed (Table 18).

TABLE 18
New Jersey Inspection Schedule and Standards

			Effective Date			
Model Year of Vehicle	5 July 1972		5 July 1974		5 July 1975	
	CO(%)	HC(ppm)	CO	HC	CO	HC
1967 and before	10.0	1600	8.5	1400	7.5	1200
1968-1969	8.00	800	7.0	700	5.0	600
1970-1974	6.0	600	5.0	500	4.0	400
1975 and later	to be set by amendment					

In addition, compulsory maintenance with reinspection of cars sent for repair/adjustment will not start until 5 July 1973. The first year will be used to educate the public and to upgrade the service industry.

Selection of the Maintenance Method

Maintenance methods for the probable 1975-1976 emission-control systems have been classified in a previous section. Any of the first three can be used for mandatory maintenance in a system designed to control just the average emissions. The second and third can be used for mandatory maintenance in a system designed to control the emissions from every car. The fourth, fifth, and sixth methods, which depend on engineering changes, will not be discussed here.

If the purpose is only to minimize emissions, periodic maintenance of all cars including preventive maintenance (method 3) is an attractive choice. This approach would require no special inspection facilities owned by the state, but it would require careful surveillance of privately owned garages and additional equipment in these garages. Its main advantage may lie in the preventive maintenance, since studies have shown that the emissions from cars that have been adjusted without preventive maintenance are back to the former emission levels in about 6 months.

Requiring the garages to adjust each car to manufacturer's specifications when performing any maintenance (method 1) also does not require state-owned facilities and also requires close supervision. Preventive maintenance could be part of this method, and, with this addition, this method only differs from the one first discussed by being voluntary and sporadic instead of mandatory and periodic.

Periodic inspection of all cars and maintenance of those cars that have emissions exceeding preset standards (method 2) is the method usually meant by an inspection/maintenance system. This system can be operated on three bases: inspection and maintenance in state facilities, inspection in state facilities and maintenance in privately-owned garages, and inspection and maintenance in privately-owned garages licensed or franchised by the state. The second of the three choices is the usual one, principally because of the public distrust of the service industry, which causes the public to prefer inspection by the state. The first one is not chosen because of the reluctance of the state to compete with private enterprise and because of the many complications connected with building state-owned repair facilities. This method often includes reinspection of cars sent for maintenance, but this is not necessary unless there is a legal requirement to meet specified standards.

If the method selected must also include enforcement of the individual car warranty, it will be built around the test specified by EPA. It is usually assumed that this will be some type of short emissions test, but Section 207 of the Act would allow the Administrator to decide that functional tests, on the components, correlated reasonably well with the results of the CVS-1975 test. It is conceivable that these could be done in privately-owned facilities, but the official nature of the warranty test and its consequences make a state-owned inspection lane the obvious choice.

Selection of Tests

If the maintenance method includes enforcing the individual-car warranty, EPA will select the primary test, but all of the methods will probably use a variety of tests. Both diagnostic and exhaust emission tests will be part of any method. Some type of emissions test will be used either to ensure satisfactory maintenance or as a diagnostic aid. Diagnostic tests are an integral part of maintenance work by a mechanic, which is the only operation that reduces emissions.

The ideal emissions test would

1. Determine the amounts of pollutants emitted in actual use
2. Pass and fail the same cars as the CVS-1975 test
3. Pass and fail the same cars as the warranty test
4. Be short
5. Require only reliable and inexpensive equipment
6. Furnish diagnostic information on malfunctions

Previous discussion has covered the reasons why Items 1 and 2 are unattainable and the hazards of basing a warranty on a short hot-start test. The list is then reduced to the last three (Item 3 included, if warranty enforcement is included) and

7. Give reasonable reliability in selecting the cars that require maintenance

is substituted for Items 1 and 2. There are several tests that satisfy these criteria (see Appendix B) reasonably well and these tests differ principally in the relative emphasis put on time and cost of equipment on one hand and diagnostic information on the other hand.

Inspection lanes select the vehicles needing maintenance but otherwise do nothing to reduce emissions unless the results assist or control the mechanics. Inspection lanes can assist and control the mechanics in four ways. They

1. Isolate vehicles with excessive emissions (those needing maintenance);
2. Isolate vehicles with excessive emissions and give a partial diagnosis to help the mechanics get started;
3. Provide a complete diagnosis of maintenance needed on vehicles with excessive emissions; and
4. Ensure that maintenance is complete and correct.

A study by Northrop Corporation (30) for the State of California found that a schedule of diagnostic tests was not a cost-effective inspection system for selecting cars to be sent for maintenance elsewhere. The study showed that exhaust emission tests by a short dynamometer test (Key Mode) or an idle test gave partial diagnostic information and were more cost effective. Partial diagnostic information was given to the mechanic to assist him in the final diagnosis.

However, the ability of emissions tests to detect malfunctions is open to question. The data shown in Table 19 are some supplied by

TABLE 19 RATIO OF DETECTED FAILURES TO KNOWN DEFECTS

	INDUCED DEFECT	Idle Test 3-Sec Sample of Exhaust			Inspection Test 7-Mode California Test			Audit Test EPA Mass Plug Two California Cycle		
		HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
1.	Set Low Idle	2/13	1/13	0/13	2/13	0/13	0/13	1/12	2/12	1/11
2.	Plug Wire Off	13/13	0/13	0/13	12/12	1/12	1/12	11/12	0/12	0/11
3.	Timing Off	1/12	0/12	0/12	1/12	0/12	2/12	3/11	0/11	0/10
4.	Choke Shut	3/9	5/9	0/9	8/8	6/8	0/8	3/6	3/6	2/6
5.	No TCS Elec.	0/13	0/13	0/13	2/13	0/13	3/13	2/11	1/11	0/10
6.	No Dist. Vacuum	0/14	0/14	0/14	0/14	0/14	0/14	0/12	0/12	0/11
7.	Full Dist. Vacuum	1/11	0/11	0/11	1/11	0/11	4/11	3/10	0/10	4/9
8.	No CCS Vacuum	2/12	0/12	0/12	1/12	0/12	0/12	2/11	0/11	0/10
9.	Change Carb.	2/11	0/11	0/11	1/11	0/11	0/11	0/10	0/10	0/9
10.	.005" Plug Gap	10/12	0/12	0/12	9/12	0/12	0/12	9/11	0/11	0/10
A.	Number failing / total tested	34/120	6/120	0/120	37/118	7/118	10/118	34/106	6/106	7/97
B.	Number failing / number tested in 1,2,3,4,8,9, & 10	33/94	6/94	-	34/80	7/80	-	29/73	5/73	-
C.	Number failing / number tested in 5,6, & 7	-	-	0/38	-	-	7/38	-	-	4/30

GM to the California ARB. Defects known to affect emissions were put into a group of vehicles and the emissions were measured by three methods: idle, California 7-mode, and the official EPA test for 1971 (CVS for HC and CO and two California hot-start cycles for NO_x). The data shown are expressed as detected failures versus known defects. "Detected failures" mean the cars having emissions above the standards. The data are summarized at the bottom in terms of detected failures versus total having defects (line A), detected failures for HC and/or CO versus total having defects known to affect HC and CO (line B), and detected failures versus total having defects known to affect NO_x emission (line C).

These three tests are equivalent within probable error in detecting defects primarily affecting hydrocarbon and carbon monoxide emissions, and they are all poor. The 7-mode hot-start method is superior to the idle test in detecting defects primarily affecting NO_x emissions, but it only detects about 15 percent of them. There is evidence of interaction between defects; e.g., so-called NO defects affect hydrocarbon emission, and vice versa. Evidence for interaction was also found in the APRAC CAPE-13 project.

The question immediately arises, Why worry about these defects if they do not cause the cars to exceed the standards? This argument is fallacious if the objective is to reduce average or total emissions. These defects were chosen as ones known to occur and known to affect emissions. Consequently, if a particular car with one of these defects can still comply with the standards, it would emit even less with the defect corrected. Hence, correction of these defects will reduce average emissions in actual use and something other than an emissions test is needed. Good functional tests would obviously detect most of these defects.

Diagnostic tests could be useful in inspection lanes if they provided complete information on engine and control-system failures and operation. This could be accomplished by an automatic and computerized diagnostic console programmed to accomplish quickly and inexpensively the following:

1. Functional tests showing that the engine and/or the control system are not within specifications where it is known that the combined system will meet the standards.

2. Diagnostic tests showing what parts need to be checked and/or replaced.

The mechanics in the service industry could be trained to understand and use the information supplied by the inspection lane diagnoses.

Selection of Maintenance Standards

If the method chosen is inspection of all cars and designation for maintenance of those cars not meeting specified standards, there is a strong incentive to maximize emission reduction by sending a high percentage of cars for maintenance. There are, however, considerations that temper this simplistic approach, and the items that should be considered in selecting the inspection standards are the following:

1. Improvement in air quality
2. Cost effectiveness
3. Percentage of second and third rejections
4. Load on the service industry
5. Percentage of cars that cannot meet the standards even with maintenance

The incentive for maximizing Item 1 has already been mentioned. As more and more cars are properly maintained, the gain in air quality per dollar spent on inspection decreases, i.e., the cost-effectiveness decreases.

Suitability for Future Control Devices

It seems obvious that any inspection/maintenance system put into operation at this time should be suitable for the maintenance of the devices to be used on the 1975-1976 cars. Actually the introduction of the 1975 models will occur in August 1974. The fact is that only the most cursory attention has been paid to this important point in most if not all of the programs under development. It is hardly mentioned in the writeups and it has not been stressed during Panel visits. This question will probably involve more than just minor adjustments in the system, since there are valid reasons to question whether any system based on annual correction of malfunctions can keep the new devices working well enough to ensure that the standards will be met in actual use.

The Key Mode and idle approach were reasonably effective in the Northrop study for correcting the major emissions problems in present cars, but they may not be adequate for controlling 1975-1976 cars to much lower emission levels because there is no short test precise enough to give a pass or fail that is meaningful in terms of meeting 1975-1976 standards. 1975-1976 cars will require a much more thorough diagnosis of the complete emission control system.

There have been several studies of the emission reductions as a function of the percentage of the present cars sent for maintenance after testing. These studies have shown that larger reductions in emissions are achieved by adjusting only the higher emitters and leaving the remainder of the population alone. Cars sent for maintenance were adjusted to manufacturer's specifications. Consequently, the emissions from a significant number of low emitters were increased by being adjusted to manufacturer's specifications.

The results of these studies are often used to support the argument that inspecting all cars and adjusting just the high emitters will be a better maintenance method for 1975-1976 cars than periodically maintaining all cars, including preventive maintenance. There are three flaws in this argument:

1. Manufacturer's specifications for 1975-1976 cars will probably be at or very near minimum emissions, so adjusting all cars to these specs will probably not increase emissions from even the low

emitters.

2. If all cars are periodically maintained by a well trained and equipped service industry, adjustments on properly-functioning cars will not be changed.

3. Preventive maintenance may add significantly to the emission reduction averaged over the maintenance interval.

COST OF MAINTENANCE

Costs are estimated by using 1971 costs as a base. The cost of the emission-related parts per year for 1971 has been estimated in three ways. Two part-by-part estimates of the annual parts cost gave $35 and $53 (see Appendix C). In 1971 automotive equipment wholesalers had sales of approximately $13 billion, or $130 per car. It has been estimated that between 33 and 40 percent of these sales were emission-related parts, or $45 per car wholesale, which, with an average mark-up of 35 percent, gives $70 per car per year retail. The middle one of the three values ($35, $53, and $70) will be used in the discussion that follows.

In the section on Deterioration of Adjustments and Components, 96 emission-related parts were considered for 1975-1976 cars. Six were major items and, of the other 90, 14 were new components representing approximately a 15 percent increase in number. The durability estimates indicated a 5/8 life ratio for new versus old components. Combination of the increase in number and the decrease in life gives a 24 percent increase in parts cost for 1975-1976 compared with 1971 vehicles. This is an increase of $13 per year on the basis of $53 or a parts cost of $66 per year per car for 1975-1976.

The cost of catalyst replacement should be considered separately. At this time it appears that a 1975 car will need a catalyst replacement every other year, and a 1976 car will need one catalyst replacement every year. Replacement catalyst costs have been quoted at $15 to $20 for pellets and about $50 for monolith plus container. If the $20 value is used, a minimum total parts cost of $76 per year for 1975 cars and $86 for 1976 cars is predicted, or $23 and $33 increases for 1975 and 1976 over the 1971 cost.

Although there was a fairly wide range in dollar amounts, the percentage increase is probably fairly accurate. This represents an increase of 44 percent for 1975 cars and 62 percent for 1976 over the cost of 1971 maintenance. It should be kept in mind that many components are considered in the 1971 cost because they are emission-related but were already a part of uncontrolled vehicles. About three-fourths of the 1975 cost increase will come between the 1974 and 1975 models.

Information submitted by automobile manufacturers to the CMVE showed a range of increased maintenance cost for 1975 vehicles to be from $8.50 to $80 with a sales weighted value of $24. If the $23 increase given above for 1975 cars is scaled up by including labor costs (2/3 of parts in tuneup) the 1975 maintenance cost would be $39 over the 1971 value. These estimates are approximate enough so that $24 and $39 should be considered reasonable agreement. A similar scale up of 1976 maintenance costs would give an additional $55 per year.

From the fact that 60 percent of the cost of tuneup type work is for parts, the additional maintenance costs for emission controls can be calculated from the parts cost estimates previously given. Another approach is to take the average added cost of emission control hardware given in Table 6-2 of the CMVE January 1972 report and divide it by the average life of 5 years estimated for new emission parts to get an annual replacement parts cost. Both of these estimates are given in Table 20.

TABLE 20 Comparison of Cost Estimates of Emission Hardware

	Emission Hardware, CMVE 1972 Report			Parts from this report		Maint. (P&L)
Model Year	Cost $	Replacement Cost (1/5) $	Increase $ over 1971	Cost $	Increase $ over 1971	Increase $ over 1971
1971-72	40	8	0	53	0	0
1973-74	110	22	14	60	7	12-23
1975	314	63	55	76	23	38-90
1976	400[a]	80	72	86	33	55-120

[a] Panel 2 estimate

Periodic inspection in a State lane would add between $2 and $5 per year. No credit is taken for increase in mileage resulting from tune-up, since different operations will have opposite and balancing effects.

POSSIBLE ENGINEERING CHANGES

The section on Classification of Maintenance Methods listed three methods that cannot be applied to the probable 1975-1976 control systems. These were

1. Prescribed maintenance at pre-determined intervals
2. Signals indicating malfunctions of critical control components
3. Emission control systems that degrade vehicle performance when malfunctions occur

This section will discuss briefly some engineering changes that might make these methods applicable and thereby improve the probability of meeting the standards in use.

The first such change, precise control of A/F with a feedback loop, is under development, probably by many organizations, but certainly by Bosch, Bendix, and UOP. Aside from the feasibility of meeting the 1976 standards with a 3-way catalyst and this A/F control, this system has several possible maintenance advantages. It would eliminate the serious performance and fuel penalties inherent in other NO_x control methods and thereby remove the advantage, from the owner's viewpoint, of an inoperative control system. It seems probable that this system would have an even stronger affect; since an A/F near stoichiometry results in almost optimum performance, any malfunction might easily degrade performance so that the owner would be motivated to get the emission control system fixed.

Since such a feedback loop makes the engine essentially self-tuning, this approach should also eliminate a large fraction of the inherent variability between individual vehicles that results from manufacturing tolerances. There is also the possibility that operational variabilities resulting from variations in driving habits, fuel composition, and atmospheric parameters, and induction system deterioration will be largely eliminated. Thus a larger fraction of cars might operate as designed and hence pollute less.

Excessive catalyst temperature caused by the simultaneous presence of excess oxygen and large amounts of combustibles should also be eliminated since neither rich mixture nor secondary air is required. Susceptibility to high temperature caused by sustained ignition misfire, however, would not be eliminated in carbureted systems but could be eliminated in fuel injection systems by not injecting fuel into the misfiring cylinder.

Finally, since the system includes an electronic control circuit, installation of signals for malfunctions and controlled degradation of performance should be relatively easy. It thus appears that close control of A/F ratio with a 3-way catalyst might make possible the last two maintenance methods listed above.

The second possible engineering change that might increase the probability of meeting the standards in use is perhaps more accurately described as a change in philosophy. If the manufacturers would devote their total resources to the development of a control system for one or two engine sizes instead of a large engine family, it would be possible to select and use the lowest emission engines, thus providing a margin below the standard for deterioration on the road. It would also greatly reduce the effort, current problems, and cost of maintaining emissions below the standard by

1. Simplifying mechanic training
2. Reducing the new parts inventory
3. Limiting the amount of test equipment needed by garages, and
4. Decreasing the number of surveillance tests needed to isolate and correct field problems

As part of the above approach, or separate from it, manufacturers could also increase the chances of compliance by designing specifically for easy maintenance and increased durability of components whose failure is known to contribute to catalyst overtemperature. Examples are

1. Metal-shielded ignition wires and better connections. Manufacturers already plan to eliminate contact points in the distributor
2. Design for quick and inexpensive catalyst change
3. Provide test connections for quick determination of the condition of the control system
4. Design the control system for easy service and repair

Restriction of effort to fewer engine sizes might also make possible quality control, based on failure mode analysis, to ensure the manufacture of cars that adhere precisely to a known low-emission configuration. If this were achieved and proved by in-use surveillance, emissions could be kept in compliance by prescribed maintenance at predetermined intervals.

Noncatalytic Systems

It has already been noted that the catalysts are the most sensitive and fragile components in the probable 1975-1976 emission control systems. Consequently, control systems that do not include catalysts are almost automatically easier to maintain and more likely to behave in use as they did during certification. Perhaps the most promising noncatalytic system is the three-valve stratified-charge engine. The third valve and second carburetor might make it marginally more difficult to maintain than a 1971 car but certainly significantly easier to maintain than any of the proposed catalytic systems.

Diesels are now made that can meet the 1975 standards. These engines are noted for their long life and trouble-free operation. For the 50,000 miles defined as "useful life" in the Act, these cars should be easier to maintain than even the 1971 gasoline IC engines.

It has been possible to control the emissions from single-rotor Wankel engines to 1975 standards with thermal reactors. Although there are some materials problems connected with the necessary high-temperature operation, these cars should be easier to maintain than catalytic systems.

It seems feasible to meet 1976 standards with all of these systems, probably by the addition of EGR. The first two systems do not entail as much fuel penalty as dual-catalyst systems.

5. ANALYSIS OF EVIDENCE ON FEASIBILITY

This Panel is of the unanimous opinion that the probable 1975-1976 vehicles that depend on catalysts (dual in 1976) for emission control will not meet the standards in actual use. The Panel is also of the unanimous opinion that there is no feasible method of ensuring that these probable systems meet the standards in use. This opinion would still be held by the Panel even if the service industry were properly trained and equipped and if state programs for enforcing mandatory maintenance at reasonable intervals were in operation by 1 January 1975.

No single piece of evidence leads irrevocably to these conclusions, but the sum of all the evidence and the interactions between the various items of evidence do.

1. Mandatory maintenance. The Panel believes that mandatory maintenance of the 1975-1976 systems is essential. In the opinion of the Panel, mandatory maintenance is necessary to achieve maximum benefit, and possibly even to achieve significant benefit, from the proposed system but it is not sufficient to ensure meeting the standards in use, if the maintenance interval is realistic. Satisfactory mandatory maintenance systems will not be in operation in most of the states before 1977, on the assumption of best efforts starting now.

2. Service industry. The present service industry is inadequate and will remain so until state programs of mandatory maintenance are operating on an enforceable basis, including the training and licensing of mechanics.

3. Durability of control systems. Many of the elements in 1975-1976 control systems are significantly less durable than present control hardware. This evaluation is particularly applicable to catalysts but it applies also to such items as the complicated new carburetors, the auxiliary-air switching system and the EGR devices. In spite of the fact that the Certification Procedure is less stringent

than in real life, consistent performance for 50,000 miles has not been demonstrated in this test for the oxidation catalysts and the reduction catalysts have almost all failed before 50,000 miles. The argument that these difficulties will be corrected with more experience ignores the vast background of experience with similar catalysts. The EGR systems and the new carburetors should not be as fragile as the catalysts but they will certainly be less durable than present components.

4. Deterioration rates. Most of the manufacturers planning on the use of catalysts have values of about one-half the official standards as engineering targets for the production prototype vehicles at the time they start the Certification Procedure. This assumes a deterioration factor of 2 to cover all the slippage between prototypes and production vehicles and all the deterioration in use for 50,000 miles. This low a deterioration plus slippage factor has not been achieved for catalytic systems, and is actually seldom approached.

5. Effect of untreated exhaust. In catalytic control systems, the exhaust that escapes to the atmosphere untreated, either through leakage or because the catalyst is inoperative, is from 10 to 20 times richer in pollutants than treated exhaust. Consequently, if the standards are to be met the percentage of inoperative catalysts at any instant must be held to a very low value--a value much below what is attainable by periodic maintenance at any acceptable intervals--even every three months. Seepage has also effectively eliminated by-pass valves as catalyst protection devices.

6. Effects of lubes and fuels. The proposed catalysts are easily poisoned by trace amounts of materials now in gasoline and lubricating oils. Even though fuels and lubes free from such materials will be supplied, the chances for accidental poisoning during the first few years of the program are great.

7. Parts Supply. The effects of off-specification parts will be larger in the 1975-1976 systems which must operate within narrower tolerance limits to be effective.

8. Deterioration Experience. Experience with present cars indicates that significant percentages do not meet the applicable standards at low-to-medium mileage. There are indications that the results of maintenance disappear in 6 months or less. Engineering judgment leads to the belief that the more complicated 1975-1976 systems will deteriorate more rapidly.

The above firm opinions of the Panel that the proposed 1975-1976 systems will not meet the standards in use and that there is no feasible method of ensuring that they do should not be interpreted as indicating that the Panel believes that the control systems will not reduce emissions significantly or that maintenance is not worthwhile. The Panel believes that mandatory maintenance is essential and that the systems will reduce the automotive contribution to the pollutant burden.

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APPENDIXES

APPENDIX A Quality Control--Functional Tests

The following table lists some typical functional tests performed during manufacture and assembly of the engine and emission control components. Although this listing covers only a few of the component and system checks made, this type of functional testing is applied to all components and partially assembled systems during the manufacturing process.

Specific tests and their application during manufacturing depend on the specific components and systems used. Included in the listing following are typical functional tests or operations used for the distributor, CEC solenoid valve, idle stop solenoid, TCS solenoid valve, engine assembly, and final car assembly.

TABLE A-1 FUNCTIONAL TESTS

DISTRIBUTOR

Manufacturing Plant Inspection

100% Mechanical	Dwell angle Rotor alignment with respect to gear Synchronism error of breaker cam Centrifugal advance curve Vacuum advance curve
100% Visual	Lubrication Appearance Correct assembly
Audit (Samples taken from shipping containers)	Disassembly and visual examination of complete units sampled during each model run

Laboratory Examination and Endurance Testing
(Test samples are selected at random from finished assemblies)

Electrical	Condenser capacitance Distributor insulation resistance
Mechanical	Rotation (clockwise or counter-clockwise) Shaft end play between housing and gear Contact alignment Point opening Dwell angle Synchronism error of breaker cam Centrifugal advance curve Vacuum advance curve Rotor alignment with respect to gear
Visual	Lubrication Appearance Correct assembly
Endurance	168 hours. Distributor speed cycled 6 times a minute from 2,000 to 500 rpm; circuit breaker plate advanced and retarded by vacuum unit 6 cycles per minute; operated with ½" spark gap in secondary circuit.

TABLE A-1 FUNCTIONAL TESTS (cont.)

COMBINATION EMISSION CONTROL (CEC) SOLENOID VALVE

Manufacturing Plant Inspection

100% Electrical	Current at 8 volts
100% Mechanical	Plunger actuation Minimum hold-in force of plunger Vacuum leakage Air flow through valve Minimum torque on bolt
100% Visual	Welds, staking, appearance, wire placement, sealer, bolt height
Audit (Samples taken from shipping containers)	Completed valves inspected for plunger travel, bolt height, prevailing bolt torque and visual defects; functional characteristics checked by hand test

Laboratory Examination and Endurance Testing

(Test samples are selected at random from finished assemblies)

Electrical	Current at 8 volts before and after endurance; insulation resistance - 500-volt terminal to case; pull-in voltage of plunger before and after endurance
Mechanical	Bolt setting - case to end of bolt dimension - before and after endurance Plunger travel before and after endurance Hold-in force of plunger at 8 volts Torque to move bolt from set position - after endurance Vacuum leakage energized and deenergized before and after endurance
Visual	Welds, staking, appearance, terminal alignment, sealer
Endurance	50,000 cycles. One cycle consists of 4 seconds energized and 3 seconds deenergized with distributor vacuum control in vacuum circuit.

TABLE A-1 FUNCTIONAL TESTS (cont.)

IDLE STOP SOLENOID

Manufacturing Plant Inspection

100% Electrical	Current at 7 volts
100% Mechanical	Bolt setting - case to end of bolt dimension Plunger actuation Minimum hold-in force of plunger
100% Visual	Welds, staking, appearance, wire placement, sealer
Audit (Samples taken from shipping containers)	Completed valves inspected for plunger travel, bolt height, and visual defects; functional characteristics checked by hand test

Laboratory Examination and Endurance Testing
(Test samples are selected at random from finished assemblies)

Electrical	Current at 7 volts before and after endurance; pull-in voltage of plunger before and after endurance
Mechanical	Bolt setting - case or mounting flange to end of bolt dimension - before and after endurance Plunger travel before and after endurance Hold-in force of plunger is 7 volts before and after endurance Torque to move bolt from set position - after endurance 90° bend of terminal after endurance to check for lead breakage
Visual	Welds, staking, appearance, terminal alignment, sealer
Endurance	50,000 cycles. One cycle consists of 4 seconds energized with a 5 pound load and 3 seconds deenergized.

TABLE A-1 FUNCTIONAL TESTS (cont.)

TRANSMISSION CONTROLLED SPARK (TCS) SOLENOID VALVE

Manufacturing Plant Inspection

100% Electrical	Current at 8 volts
100% Mechanical	Vacuum leakage Plugged vacuum ports
100% Visual	Welds, staking, appearance, wire placement, sealer
Audit (Samples taken from shipping containers)	Completed valves inspected for plunger travel, bolt height, and visual defects; functional characteristics checked by hand test

Laboratory Examination and Endurance Testing

(Test samples are selected at random from finished assemblies)

Electrical	Current at 8 volts before and after endurance; insulation resistance - 500 volts terminal to case; pull-in voltage of plunger before and after endurance
Mechanical	Vacuum leakage energized and deenergized before and after endurance
Visual	Welds, staking, appearance, terminal alignment, sealer
Endurance	25,000 cycles. One cycle consists of 1.5 seconds energized and 1.5 seconds deenergized with distributor vacuum control in vacuum circuit.

TABLE A-1 FUNCTIONAL TESTS (cont.)

ENGINE ASSEMBLY - INSPECTIONS AND TESTS

100% Mechanical

1. Air motoring - consists of running engine in reverse, than forward; check for proper overhead operation, unusual noise; set timing visually with timing light; balance engine.
2. Compression test - this test is performed on each cylinder by cranking engine with starter.
3. Exhaust manifold check - this test verifies that the manifolds and all related passages are sealed.
4. Anti-dieseling switch - switch is electrically energized to check proper operation and set carburetor RPM.
5. Exhaust gas recirculation valve - visually check for presence, proper gasket, and location; vacuum is applied to observe valve function.
6. Engine hot test - each engine is run approximately 6 minutes to check proper operation.
7. Transmission control switch - switch is electrically energized in hot test to see if engine RPM increases and engine torques over.
8. Engine RPM drop - consists of a power balance test during engine hot-test running.
9. Each cylinder head is checked for proper air passages on A.I.R. equipped cars.
10. Intake manifolds - EGR manifolds are thoroughly checked to see that all passages are open and appropriate flow rates exist through each passage.

Audit (Randomly Sampled)

1. Adcole cam checking device - checks lobes and cam in general for proper dimensions.
2. Emission testing - selected engines are audited for HC, CO, NO_x emissions using California 7-cycle hot test.
3. Compression ratio check - engines are audited using the whistle test for proper compression ratio.

TABLE A-1 FUNCTIONAL TESTS (cont.)

4. Engine durability testing - five dynamometer cells' engines are tested each day on a short 1-hour test program and two engines are tested on a 12-hour full horsepower load test. These engines are then disassembled and reviewed for proper assembly.

FINAL CAR ASSEMBLY - INSPECTIONS AND TESTS

100% Mechanical

1. A.I.R. Diverter Valve - note any air leakage from valve silencer, check operation and timing function of valve.
2. Engine RPM - Monitor final car engine RPM with proximity detector.
3. TCS Inspection - Visually verify TCS wiring and check switch function by detecting proper current in TCS wiring.

Audit (Randomly Sampled)

Conduct complete cold-start EPA exhaust emission test and monitor such operations as TCS, EGR, A.I.R., and transmission shifts. Inspect vehicle for proper component assembly, engine RPM, timing, dwell, idle smoothness, etc.

APPENDIX B SHORT TESTS

SHORT EMISSION TESTS

As many as 16 short emissions tests have been proposed. Each has some capability of diagnosing engine or parameter malfunctions that affect emissions. Gross malfunctions are easily detected and diagnosed by the shorter emission tests. However, all emission tests, including the steady states of 0, 10, ... 60, do detect as little as a 2 percent misfire.[1] The more sophisticated and longer emissions tests yield more information for diagnosing borderline malfunctions.

The following sections describe the more successful short emission tests.

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7-MODE HOT CYCLE

1. General: The 7-mode cycle was developed by the State of California (2). This cycle was the original certification procedure adopted by the Federal government (3). The last two complete cycles of the Federal 7-mode have been adopted as a short test for surveillance and inspection by California. The 7-mode hot-start cycle requires a dynamometer, appropriate sampling and analytical system for monitoring HC and CO, and an on-line computer. Although the original measurements of pollutants were in concentration, this cycle is easily "closed" and run with a constant volume sampling (CVS) system.

2. Equipment and instrumentation: A dynamometer is required to reproduce road load at 50 mph. Pollutant concentrations for HC, CO, and CO_2 exhaust emissions are measured by the usual NDIR HC and CO instrumentation.

3. Test procedure: The 7-mode hot start cycle is conducted on a vehicle that has reached engine operating temperature. The vehicle is driven onto the dynamometer by a technician, tied down, and blocked. Indolene 30 is usually used for the fuel. The sampling probe or hose connection of the analytical instruments is made to the tailpipe. The hood is raised and the variable fan placed upwind from the engine. The dynamometer is set for the correct inertia weight and the driver runs the vehicle through the following cycle of seven modes:

MODE	SPEED, MPH	TIME IN MODE SECONDS
idle	0	20
acceleration	0-25	11.5
cruise	30	15
deceleration	30-15	11
cruise	15	15
acceleration	15-30	12.5
deceleration	30-20	25

The total cycle time is 137 seconds (2 1/3 minutes). The vehicle is unblocked, and the technician returns the car to the owner.

The computer printout gives weighted average HC and CO emissions as concentrations. For a closed 7-mode cycle, the CVS system gives results in grams per mile. Pass/fail rejection levels depend on the standards for the particular model year.

The 7-mode hot start cycle has a high correlation with the 7-mode cold start because the weighting factors of the cold start are 0.35/0.65 for surveillance and end-of-line inspection.

4. Summary:

Cycle test time	137 seconds
Total inspection time	197 seconds
Number of technicians	2
Equipment	Exhaust analyzers and dynamometer
Application	California surveillance; end-of-line testing

1972 EPA CVS HOT START

1. General: The CVS Hot Start was developed from the 1972-75 EPA test (4). This short test is a repeat of the first 505 seconds of the cold start portion of the driving cycle.

FEDERAL EPA SHORT CYCLE

1. General: The EPA Short Cycle was developed from combining the various modes of the EPA test cycle. The EPA Short Cycle, using the CVS system, has 9 modes, and requires 125 seconds for the cycle (5).

GM EXIT CYCLE

1. General: General Motors Corporation developed the EXIT cycle to be used as an end-of-line test (6). GM Felt that the EXIT test satisfied the following criteria, that the test

1. Be capable of operation, with a minimum of highly trained personnel.
2. Require no special driving skills, such as the capability of following the precise cycles required in audit tests.
3. Be unaffected by driver error.
4. Be capable of completion in less than one minute.
5. Have acceptable correlation with the California cycle.
6. Require an absolute minimum of system maintenance by incorporating simplicity and ruggedness in its construction.
7. Provide diagnostic capability to indicate reasons for test failure.
8. Be a truly on-line test to minimize or eliminate additional car handling.

The EXIT test provides emissions from five steady state modes, plus diagnostic brake test results. The correlation coefficients of the EXIT test with the 7-mode are 0.8 to 0.9 (7).

2. Equipment and instrumentation: A dynamometer and exhaust gas analyzers are required. The vehicle wheel speed remains at 35 mph and the brakes are used for deceleration. A sophisticated computerized system establishes specifications for the vehicle and maintains driving at 35 mph.

3. Test procedure: The driver drives the car from the assembly line onto the dynamometer rolls. A punched card gives a description of the vehicle to the computer. The computer establishes the appropriate specifications. The driver accelerates the vehicle to 35 mph and the computer then takes over. The vehicle is then put through three zones of operation. Zone A simulates the loaded condition of a hill climb; zone B is a cruise; zone C is a deceleration; final sample is at idle, after the rolls have stopped.

4. Summary:

Cycle test time	60 seconds
Total inspection time	120 seconds
Technicians	2
Equipment	Dynamometer and exhaust gas analyzer
Application	Inactive

FORD 0-40 ACCEL

Ford Motor Company (8) developed a 0-40 Accel as a pilot program to initiate the company to the problems of assembly line testing. The 0-40 acceleration encompassed the 15 to 30 acceleration of the 7-mode cycle. Because of the heavy weighting factor (0.455) of the 15 to 30 mode there was a relatively good correlation between the results of the 0-40 short test and the 7-mode. The auto industries continue to explore short cycles for development and correlation purposes. Cycle times vary between 2 to 5 minutes.

5. Summary:

Cycle test time	45 seconds
Total inspection time	105 seconds
Technicians	2
Equipment	Dynamometer and exhaust gas analyzers
Application	Inactive

THE ACID CYCLE

1. General: The ACID cycle was developed by the State of New Jersey (9), to approximate the urban driving within a 1-minute test. The ACID cycle requires a dynamometer, a constant volume sampling system, and an on-line computer. The New Jersey program for mandatory maintenance calls for idle inspection for gross emitters in Phase 1 of their implementation and for ACID cycle inspection in Phase 2 of their implementation. The program for the Fourth Prototype of the ACID cycle is not complete, but the final system will print out suggested malfunctions or maladjustments that require maintenance to bring the exhaust emission levels into compliance with the inspection standards.

2. Equipment and instrumentation: The dynamometer is adjusted to provide an equivalent 3,000-lb fixed load. A loose fitting hose connection draws in ambient air and exhaust at a constant 100 CFM for the constant volume sampling system. The constant volume exhaust stream is measured for hydrocarbon by FID, carbon monoxide by NDIR, and NO_x by chemiluminescence. A push button programmed panel guides the driver. An on-line computer gives the integrated results as well as a diagnostic report card.

3. Test procedure: The New Jersey ACID cycle should be made after the vehicle has reached operating temperature by normal urban driving for at least 20 minutes prior to the test. The vehicle is tested using existing tire pressure and owner tank fuel. The tech-

nician drives the vehicle onto the dynamometer, and the vehicle is blocked. The vehicle is preconditioned further by accelerating to 30 mph and then allowing the vehicle to coast to a complete stop. The vehicle hood is opened. After instrument calibration, a constant volume sampling hose is fitted over each exhaust outlet. A crankcase connection is made to the dipstick hole or oil fill cap. Crankcase blowby is measured by a pressure transducer or pressure gauge. Smoke opacity of the exhaust stream is measured by a light obscuration smoke-meter.

The ACID cycle consists of the following modes:

MODE	SPEED, MPH	ELAPSED TIME
acceleration	0-30	14 seconds
cruise	30	16 seconds
deceleration	30-0	14 seconds
idle	0	16 seconds
		60 seconds

The total sampling test time is 60 seconds. The computer printout gives average values of CO and HC, as grams per mile; the maximum peak smoke density as percentage to which the light source is obstructed; and the maximum positive peak crankcase pressure in inches of water. A pass or fail answer is based on a predetermined percent of rejection. The percent rejection is determined by two factors: the availibility of the service industry to handle the volume of rejected vehicles and the capability of the service industry to maintain vehicles below the rejection cut points.

The technician drives the car off the dynamometer and returns the vehicle to the owner. Cars that fail the New Jersey ACID cycle must have corrective maintenance and pass on reinspection.

4. Summary:

Cycle test time	60 seconds
Total inspection time	180 seconds
Technicians	2
Equipment	Dynamometer and constant volume sampling
Application	Under development for Phase 2 in New Jersey

THE KEYMODE CYCLE

1. General: The Key Mode Cycle was developed by the Dynamometer Division of the Clayton Manufacturing Company (10). Three operating modes were selected to detect most of the engine malfunctions causing excess emissions. For each of the three modes there are different failure limits for HC and CO. A failure in any of the six possible measurements is cause for rejection. These failures indicate the type of engine malfunctions or adjustments to be made.

2. Equipment and instrumentation: The dynamometer must be capable of absorbing horsepower at nearly a cube of the speed change and reach 30 HP at 50 mph. Pollutant concentrations of exhaust HC and CO are measured by the usual analyzers such as the nondispersive infrared type. A driver's aid showing vehicular mph and HC and CO concentrations is required.

The report card information, the "truth chart," is an integral part of the Key Mode System. Specific items for maintenance are indicated according to which modes the vehicle has failed.

3. Test procedure: The Clayton Key Mode Cycle is made on a vehicle that has reached normal operating temperature. The owner surrenders his vehicle to the technician who drives it onto the dynamometer. A second technician blocks the vehicle, checks tire pressures, and inserts the exhaust sampling probe into the tailpipe. The vehicle is accelerated to 50 mph and the steady state values of HC and CO are recorded. The vehicle is allowed to decelerate to 30 mph and the steady state values of HC and CO are recorded. The vehicle is decelerated to idle, and values of HC and CO are recorded. The total sampling test time is approximately 1 minute.

MODE	SPEED, MPH
high cruise	50
low cruise	30
idle	0

The technician removes the sampling probe and the equipment used for blocking. The driver drives the vehicle off the dynamometer and returns the car to the owner. The HC and CO values obtained are recorded and compared with preestablished pass/fail cut points. A failure in any of the six measurements is cause for rejection. Specific instructions on the "truth chart" give instructions to the mechanic for maintenance according to the CO failure at idle, low, or high cruise. Similarly, maintenance instructions are give on the "truth charts" for correcting the malfunctions or maladjustments as indicated by the HC failures.

4. Summary:

Cycle test time	60 seconds
Total inspection time	120 seconds
Technicians	2
Equipment	Dynamometer and exhaust gas analyzers
Application	PMVI-Washington, D.C.

EPA STEADY STATE CYCLES

1. General: The EPA Administrator may approve a short emission test for purposes of state inspection as soon as a suitable test is developed that correlates with the official test. The EPA has studied various short cycles and computed the correlations of these cycles with the 1975 EPA test (11). The correlation coefficients were rarely above 0.8.

4. Summary:

Cycle test time	60 seconds (3 modes)
Total inspection time	180 seconds (CVS) 120 seconds (concentrations)
Technicians	2
Equipment	Dynamometer and exhaust gas analyzer
Application	Under development

THE IDLE TEST

Although simple idle or steady-state tests have been used for some time, their full potential was not recognized until after discriminant analyses of hot cycle data (12,13). Optimal HC, CO, and NO_x pass/fail cut points have been calculated to identify vehicles with emissions greater than given levels for assembly line or in-use vehicles.

Several idle inspection programs have included instructions for prescribed maintenance, based on the idle failure values (11,14,15).

2. Equipment and instrumentation: Suitable analyzers such as the nondispersive infrared type are appropriate for measuring the HC, CO, and NO_x pollutant concentrations.

3. Test procedure: The Idle test is made on a vehicle that has reached normal operating temperature. The transmission is placed in neutral and the owner accelerates the engine to ensure stabilization of the engine temperature. The steady state values of HC, CO, and NO_x are recorded and compared with the pass/fail criteria. If the vehicle does not pass the established emission limits, the vehicle is rejected for corrective maintenance. Guide lines for corrective maintenance may be issued according to the implementation plan.

This entire operation of testing and diagnosing has been automated by at least one auto manufacturer (16).

4. Summary:

Cycle test time	--
Total inspection time	Less than 60 seconds
Technician	1
Equipment	Exhaust gas analyzer
Aplication	PMVI: State of New Jersey, California Highway Patrol, Assembly line inspection

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APPENDIX C ESTIMATION OF EMISSION RELATED PARTS COST

1. By Alex Wong, 3 years experience as auto mechanic, 4 years as clerk in parts distributor, B.S. in ME, M.S. in Environmental Engineering.

No.	Items	Retail Price Each	Total
4	Points	$ 4.50	$ 18.00
4	Condenser	1.25	5.00
4	Rotor	1.50	6.00
2	Distributor cap	5.00	10.00
2	Ignition wire set	15.00	30.00
3	PCV valve	1.69	5.07
5	Air filter	6.50	32.50
5	Gasoline filter	1.00	5.00
5	Breather filter	1.50	7.50
1/3	Carburetor	81.00	27.00
2/3	Carburetor kit	10.00	6.60
40	Spark plugs	1.60	60.40
			$ 213.07

It was assumed the car started out new with all new parts and this represented 4 annual replacements.

The annual replacement then is $53 over the 50,000-mile or 5-year period.

2. By John N. Pattison, Ph.D., experienced in emission control research and maintenance.

No.	Items	Retail Price Each	Total
4	Points	$ 4.50	$ 18.00
4	Condenser	1.25	5.00
4.	Rotor	1.50	6.00
1	Distributor cap.	5.00	5.00
1	Ignition wire set	15.00	15.00
3	PCV valve	1.69	5.07
3	Air filter	6.50	19.50
1	Gasoline filter	1.00	1.00
2	Breather filter	1.50	3.00
1	Carburetor kit	10.00	10.00
32	Spark plugs	1.60	51.20
			$ 138.77

Also assumes the car started new and this represented 4 annual maintenance and thus covered the 50,000-mile or 5-year period at an average annual cost of $35.

Both estimates are based on a popular V-8 engine and present equipment and costs. Labor not included. Labor is estimated to cost 2/3 of parts cost or 40% of total tuneup cost.

APPENDIX D THE EFFECT OF UNTREATED EXHAUST

The first step was to obtain an estimate of pollutant concentrations in untreated exhaust. This was done by obtaining estimates of the probable emissions from 1975 and 1976 cars if specific control devices failed. The written replies from Ford and Chrysler and a summary of the telephone reply from American Motors are attached.

The estimates that have been calculated are based on several assumptions, and these are listed below:

1. The definition of meeting the standards that the Panel accepted in D.C. has been used here, namely, that the average car in use will just meet the standards at 50,000 miles or 5 years.

2. The average car at the time of manufacture (sale) or zero miles will be emitting only one-half of the standards. This is based on the observation that most of the manufacturers have engineering targets that are about one-half of the standards. Part of this difference between the engineering targets and the standards may be taken up by slippage in manufacture, but if this is so the calculations that follow just represent the most optimistic case.

3. The emissions from the average car increase linearly with age or mileage if there is not a failure of a control device. For this calculation it makes no difference whether this deterioration rate requires or does not require that the average car have one or more catalyst changes in order to have emissions just equal to the standards at the end of 50,000 miles or 5 years (see Figure D-1)

4. The car population under consideration is uniformly distributed from zero to 50,000 miles or, alternately, from zero age to 5 years, and when first driven all had on the average the emissions defined in Item 2. The number of cars in the population is immaterial as long as the number is large enough truly to represent the cars as manufactured and used. Other cars in the actual population do not enter the discussion or influence the results, since the only question is whether the 1975 and 1976 cars will meet the standards in actual use.

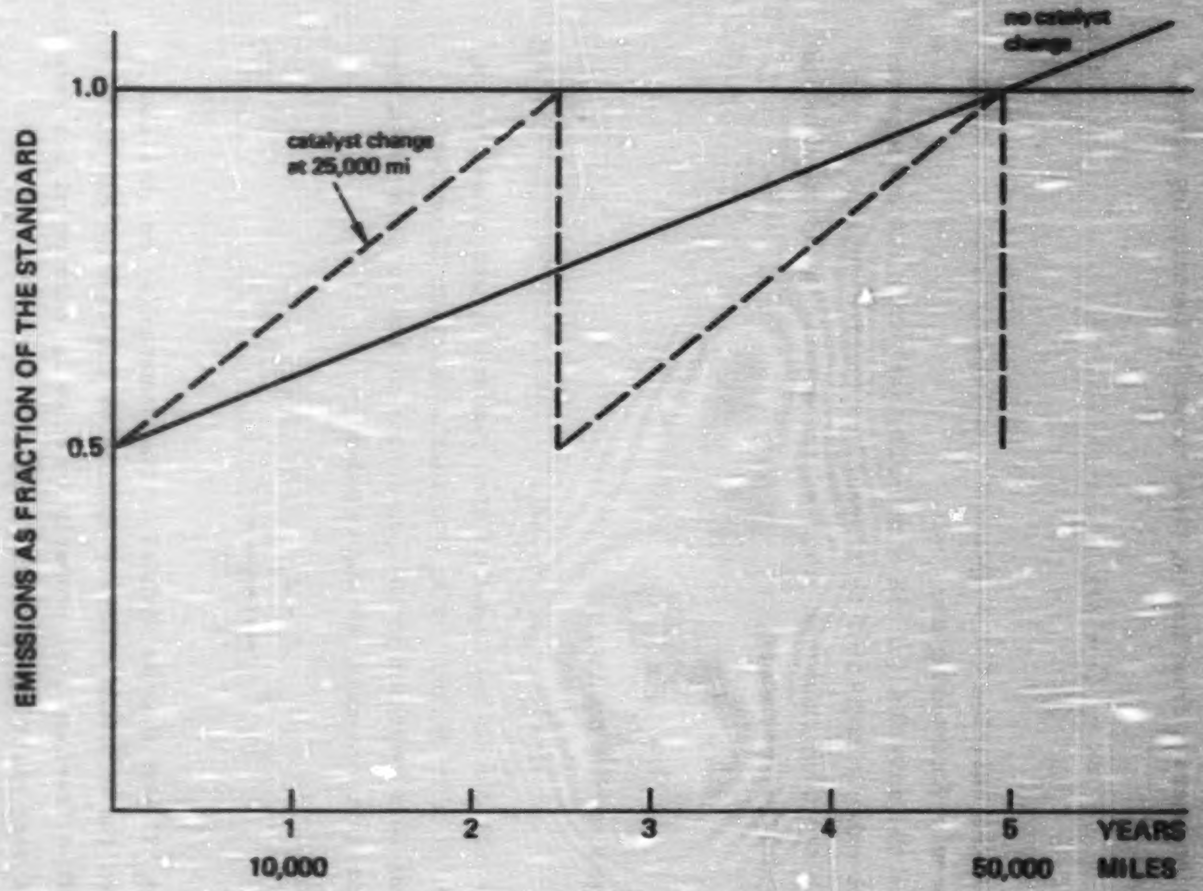

FIGURE D-1 Assumed emissions vs mileage with no catalyst change and with one catalyst change.

THE SIMPLE ALGEBRA

The emission (of a specified pollutant) from the average car in a population where a fraction, x, have properly functioning control devices is

$$ax + (1 - x)b, \qquad (1)$$

where

a is the emission (of a specified pollutant) from the average properly functioning car, and

b is the emission (of the same pollutant) from the average car with exhaust untreated by a specified control device.

If a and b are both expressed terms of the exhaust emission standard for the specified pollutant,

$$a = f_1 s$$

$$b = f_2 s$$

then expression (1) becomes

$$sx\,(f_1 - f_2) + sf_2. \qquad (2)$$

Expression (2) can be set equal to the standard(s) and solved for x. This value of x is defined as X_s and is the fraction of properly functioning cars required in the population if the emission from the average car is to be equal to the standard :

$$X_s = \frac{1 - f_2}{f_1 - f_2}. \qquad (3)$$

Expression (2) can also be divided by the standard(s) to give the fraction of the emission standard emitted by the average car in a population with a fraction x of properly functioning cars or with a fraction (1 - x) of cars emitting untreated exhaust.

EVALUATION OF f_1

Under the assumptions made, f_1 is 0.75, as can be seen in Figure D-1, which illustrates the cases of "no catalyst change in 50,000 miles" and "a change every 25,000 miles." Any number of catalyst changes that result in the average car having emissions just equal to the standards at 50,000 miles gives the same value for f_1, namely, 0.75. Catalyst life or catalyst changes resulting in emissions from the average car that are lower than the standards at 50,000 miles will give a lower value of f_1, but this is equivalent to assuming that cars appreciably cleaner than required will be manufactured. If the assumption that a catalyst change reduces the emissions to the original value of s/2 is not valid, the value of f_1 will be larger than 0.75. In other words the value chosen for f_1 is probably optimistic from the standpoint that it will give, in the calculations, a lower percentage of properly functioning cars required to meet the standards than is the case in actual practice.

EVALUATION OF f_2

Whereas f_1 is determined by the requirement that the emissions from the average car exactly equal the standards at 50,000 miles and, consequently, has the same value for all pollutants, f_2 will vary with pollutant, with the device which malfunctions, with engine size, with 1975 or 1976 systems, etc. However, an estimate sufficiently accurate for the purpose at hand does not require consideration of many of these variables and, furthermore, the accuracy of the data does not justify such complications. Consequently, the calculations will be restricted to the 1976 case and to four cases of component failure.

American Motors and Ford gave their estimates of the effects of device failure in g/mi and Chrysler gave their estimates in emission factors, i.e., directly in units of f_2. Table D-1 lists some data

TABLE D-1 FACTORS BY WHICH THE EMISSIONS FROM AMERICAN MOTORS AND FORD 1976 CARS WOULD EXCEED THE 1976 STANDARDS WITH CATALYSTS OR WITH CATALYSTS AND EGR NOT WORKING

	1976 Standards	Ford 1976 base, g/mi	col. 2 / col. 1	Amer. 1976 base, g/mi	col. 4 / col. 1	Ford '76 with EGR, g/mi	col. 6 / col. 1	Amer. '76 with EGR, g/mi	col. 8 / col. 1
HC	0.41	2.55	6.22	3.0[a]	7.32	3.17	7.73	3.0	7.32
CO	3.4	34.80	10.24	40.0[a]	11.76	45.14	13.28	40.0	11.76
NO_x	0.40	4.19	10.48	5.0	12.50	1.40	3.5	2.5	6.25

---

[a] American Motors did not give these numbers. They gave the numbers for HC and CO listed in col. 8 and said that without EGR they suspected that these values would be a little lower. This agrees with the numbers quoted by Ford.

extracted from the Ford and American Motors replies and some values of f_2 calculated from these data. It is interesting to note that the two companies agreed in their estimates remarkably well and that the calculated f_2 values also agree quite well with the direct estimates by Chrysler.

From Table D-1 and the Chrysler letter the following values of f_2 were chosen to be used in illustrative calculations.

TABLE D-2 VALUES OF f_2 FOR VARIOUS FAILURE MODES

Failure	Pollutant	f_2
Oxidation catalyst	CO	12
Oxidation catalyst	HC	7.5
Reduction catalyst	NO_x	4
Reduction catalyst and EGR	NO_x	10

From equations (3) and (4) and from the values for f_1 and f_2 the values in Tables D-3 and D-4 have been calculated.

TABLE D-3 PERCENTAGE OF PROPERLY FUNCTIONING CARS TO EXACTLY EQUAL STANDARDS

Pollutant	X_s
CO	97.8
HC	96.3
NO_x (cat. failure)	92.3
NO_x (cat. and EGR failure)	97.3

TABLE D-4 FRACTION OF EMISSION STANDARD EMITTED WITH 95 PERCENT AND 90 PERCENT PROPERLY FUNCTIONING CARS

Pollutant	F_s(95%)	F_s(90%)
CO	1.3125	1.875
HC	1.0875	1.425
NO_x (cat. failure)	0.9125	1.075
NO_x (cat. and EGR failure)	1.2125	1.675

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ENGINEERING AND RESEARCH OFFICE

CHRYSLER
CORPORATION

May 5, 1972

Mr. Robert Brattain
Post Office Box #256
Pebble Beach, California 93953

Dear Bob:

Listed below are the data which you requested on emission levels of 1975 and 1976 systems with various component failures. Emission levels of a properly working system are as follows:

	Emission Level - Grams/Mile		
	HC	CO	NOx
1975 -	0.2 to 0.6	2.0 to 5.0	1.4 to 3.0
1976 -	0.2 to 0.5	2.0 to 4.0	0.2 to 0.5

In each instance the low number represents the emission levels of a carefully adjusted research car and the higher number reflects the probable levels of a moderately maintained car with some accumulated mileage.

Estimated emission factors are tabulated below for systems with various component failures:

Year	System Condition	Emission Factors		
		HC	CO	NOx
1975	Properly working system	1.0	1.0	1.0
	Oxidation catalyst failure			
	(1) deterioration only	2.0	1.5	1.0
	(2) catastrophic failure	5.0	8.0	1.0
	EGR failure	1.2	1.0	2.0
	EGR and catalyst failure	5.0	8.0	2.0
1976	Properly working system	1.0	1.0	1.0
	NOx catalyst failure	1.4	1.5	4.0
	Oxidation catalyst failure	5.0	12.0	1.0

Year	System Condition	Emission Factors		
		HC	CO	NOx
1976 (continued)	EGR failure	1.1	1.1	2.0
	NOx catalyst and EGR failures	1.4	1.5	6.0
	NOx and oxidation catalyst failures	6.0	12.0	5.0

The product of emissions from a "properly working system" in grams per mile times the appropriate emission factor will give the estimated emission level in grams per mile.

Based on limited testing with platinum-honeycomb oxidation catalysts, high emissions have been chiefly due to the development of engine maladjustment unless, of course, the catalyst is destroyed due to overtemperatures which can also result from engine maladjustments. If the catalyst is not destroyed, correction of the maladjustment resulted in the performance of the catalyst system being largely regained. Very little is known about NOx catalyst durability at present, though it appears that faster degradation will occur.

Failures of EGR systems have been due to mechanical failure of the hardware or to plugging of the EGR orifice. I believe that both these considerations point to the importance of proper maintenance.

A car set up for a 1975 oxidation catalyst is only slightly richer than a current CAS car. If the catalyst fails and the engine is not maladjusted the HC and CO emissions will be slightly higher than that of a present CAS car.

Very truly yours,

CHRYSLER CORPORATION

George

G. A. LACY
Chief Engineer
Vehicle Emissions Control

JBE:di

Ford Motor Company

The American Road
Dearborn, Michigan 48121

May 9, 1972

Mr. R. Robert Brattain
P. O. Box 256
Pebble Beach, California 93953

Dear Mr. Brattain:

Don Jensen asked me to respond to your questions regarding the emission levels of our 1975/76 vehicles in the event that the control systems of these vehicles become defective. A year ago we might have agreed with Professor Shinnar's article in "Science" which maintained that the emission levels of a 1975 type car with defective thermal reactors and catalysts would be higher than the emission levels from present engine modification systems. However, our currently projected prime system for 1975 vehicles does not use thermal reactors and thus operates considerably leaner than a vehicle equipped with thermal reactors. As a result, the base engine emission levels of these vehicles are still below the 1972 Federal emission standards.

Your concern with the subject of malfunctioning emission control systems was also discussed at the recent EPA suspension hearings. During our testimony on April 19, we stated that the base engine emission levels from a 1975 car will not be worse than those of the 1972 model year vehicle even if all the control systems should fail (see Attachment A, transcript of proceedings).

I am enclosing the latest Riverside data which show emissions of vehicles with and without catalysts. As you can see, the base engine emission levels (without catalyst), in most instances, meet the 1973 Federal standards of 3 g/m HC, 28 g/m CO and 3.0 g/m NO_x, as converted to a 1975 CVS-CH test base (see Attachment B).

The best information we have available on the effects of EGR on base engine emissions is shown in Attachment C. These data were obtained from our 1973 Certification fleet data and show the emission levels before and after the replacement of defective EGR valves.

Finally, in response to your question about our 1976 system, I am enclosing our latest IIEC data (Attachment D). We, of course, have not selected a final system for 1976, however, this IIEC system represents one of the prime approaches we are now pursuing. The attached data show that the base emission levels of this IIEC system are still comparable to the 1972 level, even though the engine, due to tighter NO_x control, is operated somewhat richer than 1975 engines. We do not have emission data on catalyst only systems without EGR for a 1976-type system, however, a failure of any one of the emission control systems would not cause the emissions to exceed base engine or base engine plus EGR levels.

I hope these data are helpful in answering your questions. Please let me know if we can be of further assistance.

Sincerely yours,

Bruce H. Simpson

B. H. Simpson, Executive Engineer
Emissions Planning and Research

Attachments
cc: D. A. Jensen

Attachment B

RIVERSIDE FLEET
GROUP I - SINGLE CATALYST
8,000 MILE DATA
(with EGR)

Vehicle	Average 1975 CVS-CH Emission Levels (g/m)		
	HC	CO	NO_x
250 Maverick -1			
* WO/catalyst	1.65	27.85	3.34
** W/catalyst	0.72	2.33	3.42
250 Maverick -2			
WO/catalyst	1.30	27.64	3.23
W/catalyst	0.52	4.13	3.03
351C Ford -1			
WO/catalyst	0.95	24.72	2.49
W/catalyst	0.24	2.08	2.50
351C Ford -2			
WO/catalyst	1.01	30.76	2.61
W/catalyst	0.27	2.88	2.88
360 F-100 -1			
WO/catalyst	1.14	22.55	2.59
W/catalyst	0.34	2.72	2.19
460 Lincoln -1			
WO/catalyst	2.13	25.08	2.82
W/catalyst	0.72	2.88	3.11
460 Lincoln -2			
WO/catalyst	1.59	34.60	2.68
W/catalyst	0.51	4.03	2.76

* Without Catalyst
** With Catalyst

Attachment C

THE EFFECTS OF EGR VALVE CHANGES ON EMISSIONS* (1972-CVS TEST, g/m)

	Before Change			After Change		
Engine Size	HC	CO	NO_x	HC	CO	NO_x
200	3.27	26.14	2.77	2.76	24.60	1.85
200	2.57	18.80	2.96	2.64	20.78	2.51
302	3.02	25.46	3.28	3.02	27.85	1.70
302	4.50	47.97	0.98	2.71	20.12	1.97

* EGR valves were changed because of ruptured diaphragms, leakage, or suspected plugging.

Attachment D

IIEC CONCEPT VEHICLES
LOW MILEAGE DATA

CONTROL HARDWARE	1975 CVS-CH EMISSION LEVELS (g/mile)		
	HC	CO	NO_x
base engine	2.55	34.80	4.19
base engine + EGR	3.17	45.14	1.40
HC/CO catalyst (A) + NO_x catalyst (A) + EGR	0.44	1.46	0.81
HC/CO catalyst (A) + NO_x catalyst (B) + EGR	0.40	2.42	0.51
HC/CO catalyst (A) + NO_x catalyst (C) + EGR	0.41	2.16	0.75
HC/CO catalyst (A) + NO_x catalyst (C) + EGR + insulated exhaust	0.29	3.26	0.37

R. ROBERT BRATTAIN
CONSULTING: AIR POLLUTION CONTROL • INSTRUMENTAL ANALYSIS • TECHNICAL MANAGEMENT

To: PANEL 2
From: Brattain
Subject: Estimated Emissions From 1975 and 1976 American Motors Cars With the Controls Not Operating.

On 2 May Dan Hittler furnished the following information by phone.

1. At the inlet to the oxidation catalyst on 1975 cars the HC will be 2.8g/m and the CO 30g/m with the air pump working. If the air pump is not operating the values will be HC 3.3g/m and CO 40g/m.

2. The base NO_x level in 1975 cars will be 5g/m; this is with EGR not working.

3. Levels at the inlet to the reduction catalyst on 1976 cars will be HC 3.0g/m, CO 40g/m, and NO_x 2.5g/m. If the EGR is not operating the NO_x will be 5.0g/m.

4. Levels at the inlet to the oxidation catalyst on 1976 cars will be HC 2.5g/m and CO 30g/m with both the reduction catalyst and EGR working and 2.3g/m and 25g/m with EGR not working. If the reduction catalyst or the catalyst plus EGR are not working the values are as stated in item 3.

The values given in item 4 are predicated on the assumption that the reduction catalyst will be used as an oxidation catalyst during warmup by introducing extra air ahead of the reduction catalyst. As soon as the second catalyst bed(oxidation) reaches light-off temperature the extra air will be switched to an introduction point between the reduction and oxidation catalysts.

P.O. BOX 256 • PEBBLE BEACH, CALIFORNIA 93953 • PHONE (408) 624-9040

ANALYTICAL INVESTIGATION OF FEASIBILITY OF MEETING THE 1975-76 EXHAUST EMISSION STANDARDS IN ACTUAL USE

A Minority Report

by

Marian F. Chew

Member of the Panel on

Testing, Inspection, and Maintenance

Prepared for the

COMMITTEE ON MOTOR VEHICLE EMISSIONS

of the

NATIONAL ACADEMY OF SCIENCES

June 1973

June 20, 1973

Committee on Motor Vehicle Emissions
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

Gentlemen:

The final report of Panel 2 (Testing, Inspection, and Maintenance), dated June 7, 1973, has been submitted for panel approval and endorsement. Certain major changes which I have suggested during panel meetings and in previous reviews have not been incorporated in the final report. I therefore feel it my responsibility to submit the attached report. The major points of criticism are as follows:

1. The Panel 2 charge was "to investigate the feasibility of methods of ensuring..." that 1975-76 standards will be met in use. In my opinion, Panel 2, with its expertise in testing, inspection, and maintenance, should have investigated the feasibility of meeting 1975-76 standards in use.
2. The conclusions reached by the panel as listed in the Abstract appear to be based on intuition rather than fact; that is, it is not obvious in the report how available data were utilized in the assessment that meeting standards in use is not feasible.
3. A major specific criticism of the report is the cursory treatment of degradation and maintenance data. The available data on malfunctions and reductions in emissions after maintenance warranted an in-depth study of these important areas.
4. The panel never agreed on the wording of the text concerning differences between the philosophy of requiring every vehicle to have maintenance whether needed or not in a so-called program of "minimum emissions" (a term which I do not acknowledge), and the philosophy of inspection to identify vehicles for preventive maintenance or repair.

Yours truly,

Marian F. Chew

Marian F. Chew

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1 INTRODUCTION

There is no direct evidence in the form of surveillance data to show whether or not 1975-1976 standards can be met in use for 50,000 miles. There are sufficient data of present and past emission control systems to compare emissions from production vehicles with emissions from vehicles in use in order to estimate degradation from end of line to 50,000 miles. There are sufficient data to predict degradation of catalyst efficiency. There are estimates of the probability of malfunctions and the effect of malfunctions on average levels of emissions. Using these degradations and malfunction effects, one can calculate the emission levels that will be necessary for end-of-line production so that standards specified by the 1970 CAA (Clean Air Amendments) will be met at 50,000 miles. Because of these degradations, the feasibility of meeting 1975-1976 standards in use then becomes the technological feasibility of producing the emission levels necessary at end of line so that standards will be met at 50,000 miles.

The report is divided into three sections. In the first section, degradation factors for the base engine and catalyst efficiencies to 50,000 miles are developed. Assuming the standards to be the average emission levels at 50,000 miles, end-of-line emission averages are calculated using these degradation factors and efficiencies. These values assume there will be no important changes in engine degradation from present control systems.

In the second section, effects of inspection/maintenance programs on levels of emissions from vehicles in use are estimated. Effects of malfunctions on emission levels are also discussed. Again assuming that the 1975-1976 standards are the average emission levels at 50,000 miles, end of line production averages are recalculated within a system of required inspection/maintenance.

In the third section, a very rigid program of maintenance is described and evaluated. This program requires each vehicle to have unlimited testing by the official test and maintenance until each car meets the standards after maintenance is performed. End-of-line emission averages are derived for this system.

2 FEASIBILITY OF MEETING 1975-1976 STANDARDS IN USE WITH VOLUNTARY MAINTENANCE

The most probable system for controlling auto exhaust emissions to the levels required by the CAA of 1970 is the present internal combustion engine with catalytic afterburners. Both the emissions from the base engine as well as the catalyst efficiency are expected to degrade. Under the present system of maintenance, which may be called voluntary, emissions from vehicles have degraded. In this section, surveillance data will be discussed to show degradation of emissions from EOL (end of line) to 50,000 miles. Degradation of catalyst efficiency will also be evaluated. Finally, average emission levels at EOL will be calculated, taking into account the degradation of base engine and catalyst efficiency, so that at 50,000 miles standards will be met.

DEGRADATION OF EMISSIONS FROM VEHICLES IN USE

There is a great amount of surveillance data from vehicles in use (1-16). Five different classes of emission control systems will be discussed here with respect to degradation in use, and they are classified in Table 1 according to required emission levels.

During the period 1960-1972 there have been four test procedures and they will be identified as follows:

8MHS:	Eight-mode hot-start cycle (includes a 50-mph cruise) used by Auto Club Test Station Project 1961-63 (1). HC as ppm, CO as %, NO_x as ppm.
7MHS:	Seven-mode hot-start cycle, used by California for surveillance, in many

Table 1 Classification of Emission Control Systems for California

Model Year	HC	CO	NO_x
Pre-controlled vehicles	NS[a]	NS[a]	NS[a]
1966-1969 7MCS	275 ppm	1.5%	NS[a]
1970 7MCS	2.2 g/mi	23 g/mi	NS[a]
1971 7MCS	2.2 g/mi	23 g/mi	4.1 g/mi[b]
1972 CVS-72	3.2 g/mi	39 g/mi	4.5 g/mi

[a] No standard.

[b] Seven-mode hot-start for NO_x.

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studies of effects of maintenance on emissions, by Federal government, and by auto industries as an assembly line test. HC as ppm, CO as %, NO_x as ppm.

(7MHS): Closed seven-mode hot-start cycle with constant volume sampling. HC, CO, and NO_x as g/mi.

7MCS: Seven-mode cold-start cycle called 1970 FTP (Federal Test Procedure). HC as ppm, CO as %, NO_x as ppm, or HC, CO, and NO_x calculated as g/mi.

CVS-72: A closed constant volume sampling system, which measures concentrations from a bag sample; results as g/mi HC, CO, NO_x. Uses Federal Driving Cycle.

CVS-75: A closed constant volume sampling system, which measures concentrations from a bag sample; uses a cold/hot weighting, a 10-minute hot soak, and a hot restart; results as g/mi HC, CO, NO_x. Uses Federal Driving Cycle.

Test procedures will be given with data.

Degradation of Emissions from Pre-Controlled Vehicles

In 1961-1963, the Auto Club of Southern California cooperated with other agencies (1) in determining emission levels of pre-controlled vehicles. Table 2 shows average emissions from vehicles with 0-4000 miles and 40,000-60,000 miles. Because there were neither emission standards nor known emission levels at production for pre-controlled cars, the degradation factors given are for 40-60,000/0-4000 miles. For HC, degradation is 700/532, or 1.32; for CO, 3.55/3.17, or 1.12.

Some recent data, shown in Table 3, indicate that emissions from pre-controlled vehicles have equilibrated at higher levels after five years. HC degradation ranges from 1.14 to 1.61, CO degradation ranges from 0.94 to 1.18. Degradations shown in Table 3 are compared with average levels at 0-4000 from the TSP data (1). The GMHS test used for these data was run with the hood down, resulting in higher CO values.

Degradation of Emissions from 1966-1969 Controlled Vehicles

Surveillance of emissions from 1966-1969 model vehicles in use has been done extensively by the State of California (2) and others (3-15).

Degradation of emissions from 1966-1969 vehicles as measured by California is shown in Table 4. Emissions of HC at 50,000 miles compared with the standard show a ratio of 1.44 while CO emissions at 50,000 miles compared with the standard show a ratio of 1.54.

Although degradation values are comparable for both the 1966-1969 models and the pre-controlled models, the average age and mileage of the 1966-1969 models are much less than in the pre-controlled group.

Emission levels of 1966-1969 models found in other studies indicate that the population of in-use vehicles may have higher average levels than indicated by the California surveillance data. These data are shown in Table 5.

Degradation ratios were calculated using standards as the base. Degradations from standards range from 1.2 to 1.5 for HC and 1.0 to 1.6 for CO.

TABLE 2 Degradation of Emissions from Pre-Controlled Vehicles

Survey	Ref.	Test	n	Average HC ppm	Ratio to 0-4000 mi	Average CO%	Ratio to 0-4000 mi
Standard		8MHS		none		none	
0-4000 mi	1	8MHS	66	532		3.17	
40-60,000 mi	1	8MHS	242	700	1.32	3.55	1.12

Table 3 Studies of Pre-Controlled Vehicle Emissions

Study	Ref.	Test	n	Average HC ppm	Ratio to 0-4000	Average CO%	Ratio to 0-4000
Average		7MHS		773	1.45	2.76	0.87
0-4000	1	8MHS	60	532	1.00	3.17	1.00
AC-TSP	1	8MHS	1040	710	1.33	3.4	1.07
NJ-1968	4	7MHS	97	748	1.41	2.97	0.94
GM-1968	5	7MHS	213	719	1.35	2.97	0.94
AAMP-1971	9	7MHS	74	827	1.55	3.75	1.18
C-C-1971	9	7MHS	95	609	1.14	3.03	0.96
TRW-1971	10	7MHS (7MHS)	147	857 10.91	1.61	2.79 97.51	0.88
Studies of Idle Emissions:							
TRW-1971	10	Idle	147	865		6.08	
NJ-1972	11	Idle	1139	757		5.87	
ARCO-1970	12	Idle		710		4.8	
ARCO-1970	12	Idle		730/580[a]		6.3/3.9[a]	
ARCO-1971	12	Idle		760		4.9	
ARCO-1971	12	Idle		770/570[a]		6.4/3.9[a]	
ESSO-1971	13	Idle		767		4.8	
Humble-1972	13	Idle		610		3.9	

[a] Before adjustment/after adjustment of vehicles receiving carburetor adjustment.

Table 4 Degradation of Emissions from 1966-1969 Vehicles

Survey	Ref.	Test	n	Average HC ppm	Ratio to Standard	Average CO%	Ratio to Standard
Standard		7MHS		250		1.22	
0-1500 mi	2	7MHS	276	224	0.90	0.92	0.75
50,000 mi	2	7MHS	186	359	1.44	1.88	1.54

Table 5 Studies of 1966-1969 Vehicle Emissions

Study	Ref.	Test	n	Average HC ppm	Ratio to Standard	Average CO%	Ratio to Standard
Standard		7MHS		250		1.22	
ARB-1966-72	2	7MHS	11040	316	1.26	1.53	1.25
NJ-1968	4	7MHS	68	309	1.24	1.83	1.50
GM-1968	5	7MHS	228	306	1.22	1.49	1.22
ARB-1970	2	7MHS	368	334	1.34	1.50	1.23
AAMP-1971	9	7MHS	36	373	1.49	1.94	1.59
C-C-1971	9	7MHS	61	333	1.33	1.64	1.34
TRW-1971	10	7MHS	118	370	1.48	1.24	1.02
Studies of Idle Emissions:							
TRW-1971	10	Idle	117	370		3.93	
NJ-1972	11	Idle	542	422		4.50	
NJ-1972(ESSO)	13	Idle		290		4.5	
ARCO-1970	12	Idle		360		3.6	
ARCO-1970	12	Idle		560/430[a]		5.5/3.0[a]	
ARCO-1971	12	Idle		400		3.9	
ARCO-1971	12	Idle		450/340[a]		6.3/3.4[a]	
ESSO-1971	13	Idle		316		3.8	
Humble-1972	13	Idle		324		3.9	

[a] Before adjustment/after adjustment of vehicles receiving carburetor adjustment.

Degradation of Emissions from 1970 Vehicles

In 1970 further restrictions were placed on HC and CO exhaust emissions. Average levels at 0-1500 and 40-50,000 miles from California Surveillance data (2) are shown in Table 6. Degradations from standards at 0-1500 miles are 1.17 for HC and 0.86 for CO. Degradations from standards at 40-50,000 miles are 1.57 for HC and 1.83 for CO. Emissions from GM vehicles are also shown in Table 6 on a grams per mile basis. HC ratios are 1.27 at 0-4000, and 1.57 at 40-50,000 miles. CO ratios are 0.99 at 0-4000, and 1.76 at 40-50,000 miles.

Degradation of emissions from 1970 models found in maintenance studies is shown in Table 7. Vehicles in the Northrop study for AAMP (Annual Adjustment and Maintenance Program) and C-C (Certificate of Compliance) have less degradation than the TRW study. Hydrocarbon degradation from standards ranges from 1.1 to 1.5, and CO degradation ranges from 1.5 to 1.9.

Degradation of Emissions from 1971 Models

Surveillance of emissions from 1971 models by California (2) is shown in Table 8. Degradation of emissions from standards at 0-4000 is 0.89 for HC, 0.88 for CO, and 0.81 for NO_x. For GM vehicles the 0-4000-mile degradation is comparable, with 0.93 for HC, 0.65 for CO, and 0.80 for NO_x. Because there are only eight vehicles with 40-50,000 miles, degradation for mileaged cars is given as 15-50,000 miles. Ratios for the total surveillance data are 1.50 for HC, 1.25 for CO, and 0.91 for NO_x. The GM ratios are 1.24 for HC, 1.17 for CO, and 0.85 for NO_x.

Studies of 1971 models are given in Table 9 and emissions show degradations of 0.6-1.0 for HC, 0.8-1.4 for CO, and 0.7-1.0 for NO_x. These lower degradations are found in studies of vehicles with very low average mileage or vehicles less than two years of age. For example, as average mileage increased, HC, CO, and NO_x ratios increased in the two GM studies from 0.57 to 0.63 for HC, 0.81 to 0.96

Table 6 Degradations of Emissions from 1970 Vehicles

Survey	Ref.	Test	n	Average HC	Ratio to Standard	Average CO	Ratio to Standard
Standard		7MHS		150 ppm		0.8%	
0-1500	2	7MHS	204	176 ppm	1.17	0.69%	0.86
40-50,000 mi	2	7MHS	23	236 ppm	1.57	1.46%	1.83
GM Standard		7MHS		1.8 g/mi		19 g/mi	
0-4000 mi	2	7MHS	20	2.29 g/mi	1.27	18.80 g/mi	0.99
40-50,000 mi	2	7MHS	25	2.82 g/mi	1.57	33.52 g/mi	1.76

Table 7 Studies of 1970 Vehicle Emissions

Study	Ref.	Test	n	Average HC g/mi	Ratio to Standard	Average CO g/mi	Ratio to Standard
Standard		7MHS		1.8		19	
Northrop-1971	9	7MHS	32	1.94	1.08	28.95	1.52
Standard		(7MHS)		3.3		31	
TRW-1971	10	(7MHS)	32	5.01	1.52	59.98	1.93
Standard		1972CVS		4.6		47	
TRW-1971	10	1972CVS	32	6.95	1.52	91.04	1.93
Studies of Idle Emissions:				ppm HC		% CO	
TRW-1971	10	Idle	32	399		4.65	
NJ-1972	11	Idle	277	319		4.22	
ARCO-1970	12	Idle		260		2.6	
ARCO-1970	12	Idle		310/230[a]		4.4/1.5[a]	
ARCO-1971	12	Idle		340		3.5	
ARCO-1971	12	Idle		370/260[a]		5.0/1.6[a]	

[a] Before adjustment/after adjustment of vehicles receiving carburetor adjustment.

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Table 8 Degradation of Emissions from 1971 Vehicles

Study	Ref.	Test	n	Average HC g/mi	Ratio to Standard	Average CO g/mi	Ratio to Standard	Average NO_x g/mi	Ratio to Standard
Standard		7MHS		1.8		19		4.1	
0-4000	2	7MHS	95	1.61	0.89	16.70	0.88	3.32	0.81
40-50,000	2	7MHS	8	1.96	1.09	16.39	0.86	3.88	0.95
15-50,000	2	7MHS	131	2.70	1.50	23.68	1.25	3.72	0.91
GM									
0-4000	2	7MHS	47	1.68	0.93	12.43	0.65	2.27	0.55
40-50,000	2	7MHS	4	2.02	1.12	19.56	1.03	3.36	0.80
15-50,000	2	7MHS	48	2.24	1.24	22.16	1.17	3.48	0.85

Table 9 Studies of 1971 Vehicle Emissions

Study	Ref.	Test	n	Average HC g/mi	Ratio to Standard	Average CO g/mi	Ratio to Standard	Average NO_x g/mi	Ratio to Standard
Standard		1972CVS		4.6		47		6.0	
TRW (8059 Avg. mi)	10	1972CVS	150	4.44	0.96	63.42	1.35	5.95	0.99
Standard		7MCS		2.2		23		4.0	
GM(2489)	16	7MCS	143	1.26	0.57	18.7	0.81	2.81	0.70
GM(4332)	16	7MCS	127	1.38	0.63	22.1	0.96	2.85	0.71
Studies of Idle Emissions				HC ppm		CO %			
TRW-1971	10	Idle	150	240		3.34			
NJ-1972	11	Idle	281	253		3.60			
ARCO-1971	12	Idle		260		2.6			
ARCO-1971	12	Idle		340/240[a]		4.7/1.6[a]			

[a] Before adjustment/after adjustment of vehicles receiving carburetor adjustment.

for CO, and 0.70 to 0.71 for NO_x.

Degradation of Emissions from 1972 Models

California Surveillance data (2) of emissions from 1972 models is shown in Table 10. The data have been grouped by mileage intervals because of the scarcity of data near 50,000 miles. Degradation of emissions from standards at 0-4000 miles is 1.1 for HC, 0.75 for CO, and 0.86 for NO_x. Average emissions are shown for the various mileage intervals of 4-50,000 miles in Table 10. Ratios to standards of all cars with greater than 4000 miles are 1.3 for HC, 0.9 for CO, and 1.0 for NO_x. Average emissions for GM vehicles are also shown, including assembly line averages of 2044 vehicles (20). Ratios to 7MHS standards for these assembly line data are 0.59 for HC, 0.44 for CO, and 0.67 for NO_x. These same assembly line data, using the CVS 72 test, have ratios to standards of 0.64 for HC, and 0.62 for CO.

The only studies of 1972 vehicles in use to date are idle tests of the GM EOL data shown in Table 11 (1972 models, December 1971) and NJ idle tests (1972 models, August 1972). Within the time interval of approximately eight months, average idle HC emissions increased from 77 ppm to 161 ppm, and average idle CO from 0.36 percent to 2.15 percent. Idle HC distributions for both the GM and NJ data are shown in Figure 1. The 90 percentile point for the EOL idle HC is at 100 ppm, while the NJ data show 320 ppm. Idle CO distributions for both the GM and NJ data are shown in Figure 2. The 90 percentile point for the EOL idle CO is at 0.7 percent, while the NJ 90 percent point is at 5.5 percent.

EPA Degradation of Emissions

In the calculation of Federal motor emission goals for CO, HC, and NO_x, Barth (17) used concentration values for desired air quality based on health, as shown in Table 12. Barth's calculated goals have assumed that Federal standards are exceeded by vehicles in use by

Table 10 Degradation of Emissions from 1972 Models

Study	Ref.	Test	n	Average HC g/mi	Ratio to Standard	Average CO g/mi	Ratio to Standard	Average NO_x g/mi	Ratio to Standard
Standard		7MHS		1.4		16.1		3.1	
0-4000	2	7MHS	151	1.53	1.09	12.01	0.75	2.67	0.86
4-10,000	2	7MHS	86	1.46	1.04	12.53	0.78	2.89	0.93
10-20,000	2	7MHS	42	2.02[a]	1.44	15.06	0.94	3.04	0.98
20-30,000	2	7MHS	10	6.59[b]	4.70	13.40	0.84	2.94	0.95
30-40,000	2	7MHS	4	2.56	1.83	27.04	1.68	6.16	1.99
40-50,000	2	7MHS	4	2.73	1.95	38.33	2.38	3.71	1.20
Average		7MHS	297	1.78	1.27	13.20	0.82	2.86	0.92
GM									
End of Line 20		7MHS	2044	0.82	0.59	6.98	0.44	2.09	0.67
0-4000	2	7MHS	73	1.41	1.01	8.41	0.53	2.51	0.81
4-10,000	2	7MHS	43	1.41	1.01	8.53	0.53	2.65	0.85
10-20,000	2	7MHS	20	2.63	1.88	11.56	0.72	2.89	0.93
20-30,000	2	7MHS	2	2.01	1.44	15.98	1.00	2.63	0.85
30-40,000	2	7MHS	2	1.11	0.79	24.36	1.52	3.20	1.03
54,000	2	7MHS	1	1.09	0.78	4.05	0.25	2.40	0.77
GM								7MHS	
Standard		1972CVS		3.2		39		3.1	
End of Line 20		1972CVS	2044	2.06	0.64	24.2	0.62	2.09	0.67
1972 Cert. Data		1972CVS		2.0	0.63	23	0.59	2.4	0.77
1972 Gold Audit		1972CVS		2.1	0.66	27	0.69	2.2	0.71

[a] One vehicle had HC = 23 g/mi
[b] Two vehicles had HC = 22 and 24 g/mi

Table 11 Studies of 1972 Vehicle Emissions

Study	Ref.	Test	n	Average HC ppm	90% Point	Average CO%	90% Point
GM ECL	20	Idle	2044	77	100	0.36	0.8
NJ Insp.	11	Idle	196	161	300	2.15	5.5

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FIGURE I IDLE HYDROCARBON DISTRIBUTIONS OF 1972 MODELS AT END OF LINE AND IN USE

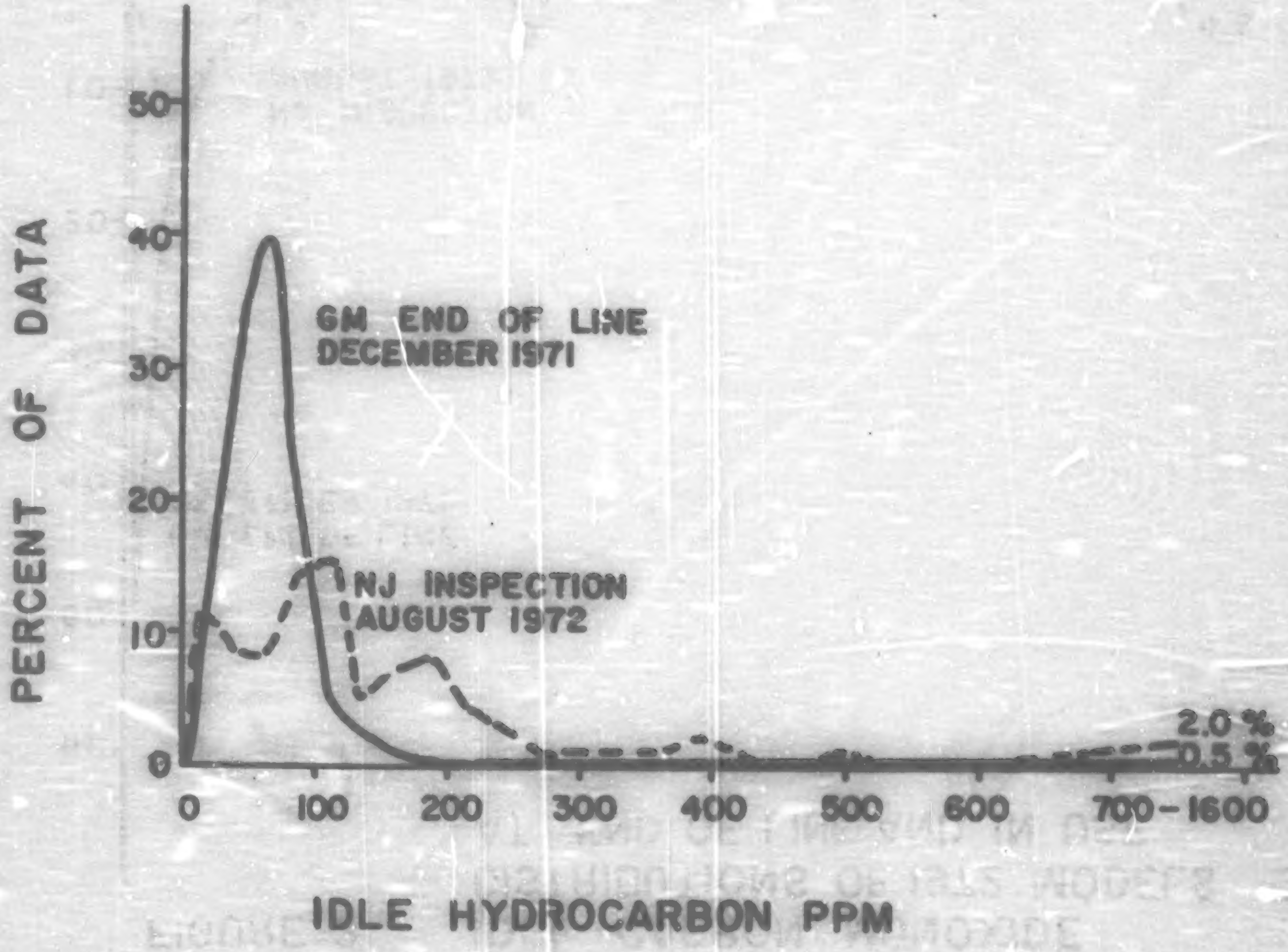

FIGURE 2 IDLE CARBON MONOXIDE DISTRIBUTIONS OF 1972 MODELS AT END OF LINE AND IN USE

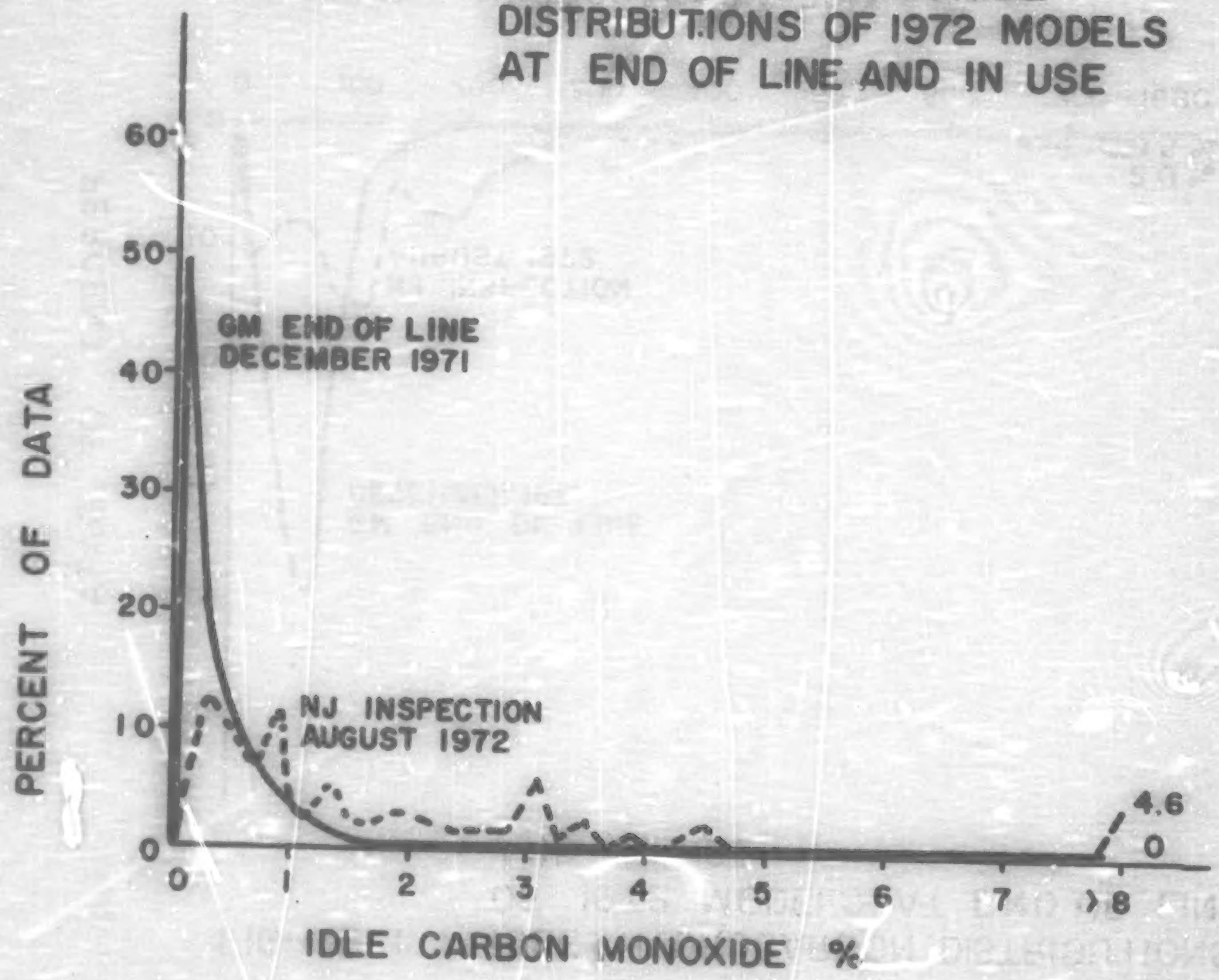

Table 12 Degradation of Emissions Assumed by EPA (8)

Pollutant	Ambient Air Quality		% Control 1967 Base	FTP 1980 Goals	Barth Degradations	Table 12 Degradations
	Conc., ppm	Avg. hr.				
CO	9	8	92.5	6.16 g/mi	1.13	0.9-1.8
Oxidants	0.06	1	—			—
NO_x	0.10	1	93.6	0.38 g/mi		0.9-1.0
HC	0.06	1	99.0	0.15 g/mi	1.25	1.4-1.6

25 percent HC and 13 percent CO. The ranges of degradations summarized in Table 13 show that vehicles in use exceed standards by as much as 40-60 percent for HC and up to 80 percent for CO. The Barth results and degradations calculated in this report are also shown in Table 12. Thus the EPA in its roll-back calculation of desired emission goals for 1980 may have assumed conservative degradation of emissions from vehicles in use.

Summary of Emission Degradations

A summary of the ranges of degradations relative to standards is shown in Table 13. Degradations at 50,000 miles relative to standards are 1.4-1.6 for HC, 0.9-1.8 for CO, and 0.9-1.0 for NO_x. It is possible that HC degradation may improve for the 1975-1976 systems because of improvement in such systems as electronic ignition or because catalysts may tend to mask minor malfunctions. However, as will be shown later, catastrophic failures of catalysts will increase degradation more than masking of malfunctions would decrease degradation. Degradation of CO emissions is not expected to be less for 1975-1976 systems unless radical changes are made in carburetion. The range shown for NO_x degradation cannot be considered to be reliable because of the data base used. The NO_x data are from vehicles with low mileage, and all vehicles were less than one to two years of age.

The degradation factors summarized in Table 13 will be used in a later section to estimate degradation of base engines of 1975-1976 systems. As mentioned above, these degradation factors will be invalid if ignition systems and carburetors are improved. These degradation factors may also be biased because most of the surveillance data used to develop the degradations came from California cars. These degradation factors have been determined on the basis of percent of required standards, that is, a ratio of emissions in use to legislated emission levels. If this percent relationship of emissions in use to standards does not hold for the low emission levels required for 1975-1976, then these degradation factors will be invalid.

Table 13 Summary of Ratios of Emission Levels to Standards

	Hydrocarbons			Carbon Monoxide			Oxides of Nitrogen		
Model Year	0-4000 Miles	Avg. of Studies	50,000 Miles	0-4000 Miles	Avg. of Studies	50,000 Miles	0-4000 Miles	Avg. of Studies	50,000 Miles
<1966	--	1.1-1.6[a]	1.32[a]	--	0.9-1.2[a]	1.12[a]			
1966-69	0.90	1.2-1.5	1.44	0.75	1.0-1.6	1.54			
1970	1.17	1.1-1.5	1.57	0.86	1.5-1.9	1.83			
1971	0.89	0.6-1.0	1.50[b]	0.88	0.8-1.4	1.25[b]	0.81	0.7-1.0	0.91[b]
1972	1.09	N.A.	1.46[c]	0.75	N.A.	0.90[c]	0.86	N.A.	0.98[c]
1966-1972 Range	0.9-1.2		1.4-1.6	0.8-0.9		0.9-1.8	0.8-0.9		0.9-1.0

[a] No standards, ratio of 50,000/4000.

[b] 15-50,000 miles.

[c] 4-50,000 miles.

CATALYST DEGRADATION

The degradation of base engine emissions of present controlled vehicles has been discussed above. In this section, the degradation of catalysts (the most probable system for emission control to meet the 1975-1976 deadlines) will be evaluated. Catalyst efficiencies from best-effort GM data (23) at zero miles and at catalyst changes and Ford data (19) at 8000 miles are summarized below. These data are from vehicles with 1975-type systems.

CATALYST EFFICIENCIES

	0 Miles (23)	8000 Miles (19)	Best-Effort Data at Changes (23)
HC	84%	67%	70%
CO	89%	89%	84%

Weighting these data by a ratio of 2:1 for GM:Ford, the following optimistic catalyst efficiencies were determined to be used as efficiencies at zero and 50,000 miles for 1975-type systems.

CATALYST EFFICIENCIES

	0 Miles	Average at Catalyst Change
HC	84%	69%
CO	89%	86%

Estimates of NO_x catalyst efficiencies at zero and 50,000 miles have been given by Gould (21) and Gulf (22). These NO_x catalyst efficiencies of 95-96% appear to be high relative to the following best-effort data* from 1976-type systems.

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* These data are summarized in the Report by the Committee on Motor Vehicle Emissions, Table 3-4, p. 39, dated February 12, 1973.

BEST-EFFORT 1976 CATALYST SYSTEMS

	Average level g/mi	Average Catalyst Efficiency
HC	0.42	NA
CO	2.5	NA
NO_x	0.64	60%

The catalyst mileages in these data range from 0 to 20,000. It should be noted that catalyst efficiencies used in the calculations of the next section are a combination of the HC and CO efficiencies determined above for 1975 systems and the NO_x catalyst efficiency determined above for 1976 systems.

Calculations

These calculations are shown in Table 14. Emissions at 50,000 miles are assumed to be the standards of 0.41 g/mi HC, 3.4 g/mi CO, and 0.4 g/mi NO_x, as required by the 1970 CAA. Using the catalyst efficiencies at 50,000 miles derived above, base engine emissions at 50,000 miles are first calculated. From the ranges of degradations, as summarized in Table 13, and the ratios of present EOL averages to standards, a total degradation factor of change in emissions from EOL to 50,000 is calculated. These factors are 2.19-2.50 for HC, 1.45-2.90 for CO, and 1.34-1.49 for NO_x. Thus base engine emissions at end-of-line production are derived, since the base engine emissions at 50,000 miles are known (as required by law). Finally, using the catalyst efficiencies at zero miles as derived above, average tail-pipe emissions at end-of-line production are calculated.

According to the calculations set forth in Table 14, it will be feasible to meet standards in use for 50,000 miles under a voluntary maintenance program if it is technologically feasible to produce average EOL vehicles with 0.085-0.098 g/mi HC, 0.92-1.84 g/mi CO, and 0.07-0.08 g/mi NO_x. These values assume that catalyst systems will degrade along the same line as cited above. However, it is unlikely that voluntary replacement of catalysts will occur as

Table 14 Estimated End-of-Line Averages for Proposed 1975-1976 Systems So That Vehicles in Use Will Meet Standards (Voluntary Maintenance)

	HC	CO	NO_x
Standards at 50,000 mi	0.41 g/mi	3.4 g/mi	0.4 g/mi
Catalyst efficiency, 50,000 mi	69%	86%	60%
Base engine, 50,000 mi	1.32 g/mi	24.3 g/mi	1
50,000 mi / standard, Table 13	1.4-1.6	0.9-1.8	0.9-1.0
End of line / standard	0.64	0.62	0.67
Total factor, EOL to 50,000	2.19-2.50	1.45-2.90	1.34-1.49
Base engine, end of line	0.53-0.61 g/mi	8.38-16.76 g/mi	0.67-0.75
Catalyst efficiency,EOL	84%	89%	90%
End of line, tail pipe	0.085-0.098 g/mi	0.92-1.84 g/mi	0.07-0.08

readily as does voluntary replacement, for example, of spark plugs. The values calculated for EOL averages are not completely accurate, but they are indicative. They are not low enough to achieve standards in use with voluntary replacement of catalysts.

Although data from the California ARB (24) indicate that approval fleet data at 4000 miles are not a good predictor of quality audit data, Figures 3 and 4 show that averages of HC and CO distributions of 50,000-mile certification cars and averages of end-of-line audit cars may not differ more from each other than by 2 percent for HC and 10 percent for CO. Because best-effort data have lower average emissions than certification data,* in the following discussion best-effort data will be compared with the calculated average emission levels necessary at EOL so that standards will be met in use. Shown below are the standards to be met at 50,000 miles as required by the CAA of 1970, the calculated average emission levels that will be necessary at EOL in order to meet standards at 50,000 miles, average emissions of best-effort data every 4000 miles, and average emissions of these same best-effort data before maintenance.

	HC g/mi	CO g/mi	NO_x g/mi
Standards to be met in use at 50,000 mi	0.41	3.4	0.40
EOL average levels so that standards will be met in use at 50,000 mi	0.09-0.10	0.92-1.84	0.21-0.24
Best-effort data (23) every 4000 mi	0.37	2.59	0.64[a]
Best-effort data (23) before maintenance	0.48	3.97	NA

[a] Best-effort data for NO_x only are summarized in the CMVE report, dated February 12, 1973.

The best-effort data above indicate that it is not technologically feasible at the present time to produce vehicles at EOL with the

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* This opinion was supported by C. J. Elder of General Motors and D. L. Hittler of American Motors.

FIGURE 3 HYDROCARBON DISTRIBUTIONS OF 1972 CERTIFICATION CARS AND QUALITY AUDIT CARS

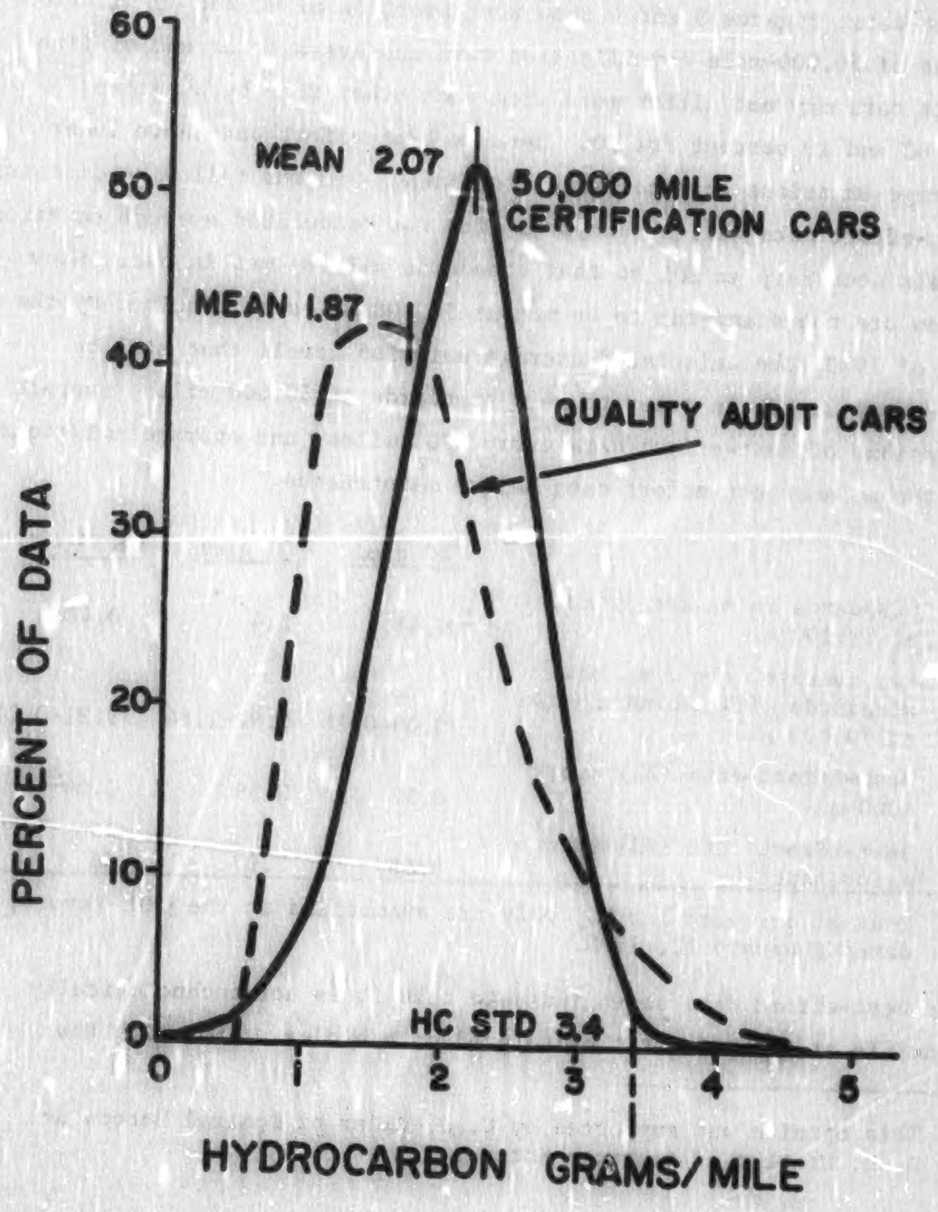

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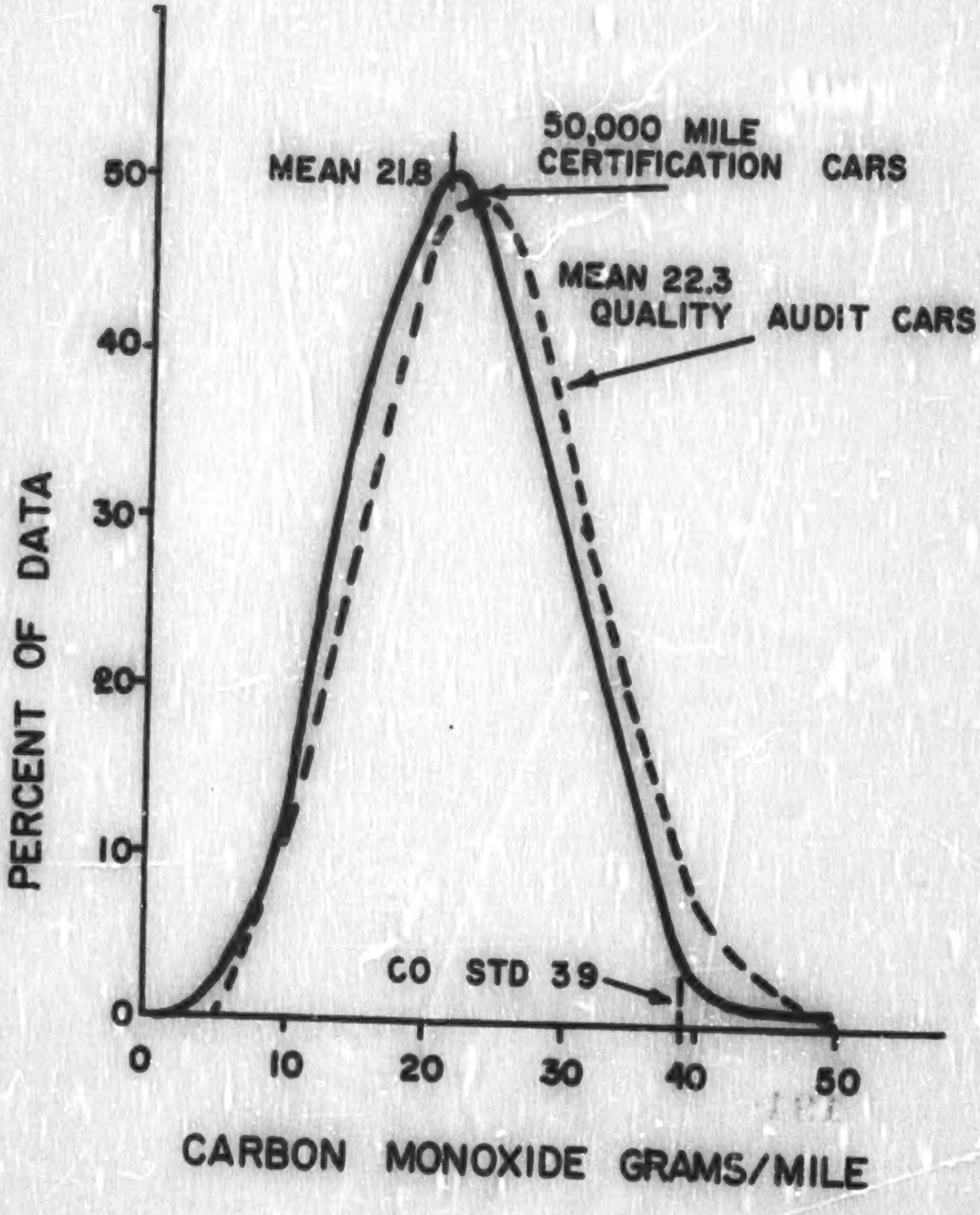
FIGURE 4 CARBON MONOXIDE DISTRIBUTIONS OF 1972 QUALITY AUDIT AND CERTIFICATION CARS



emission levels necessary to meet standards in use at 50,000 miles. The conclusion is, then, that it is not feasible to meet the required standards in use under a system of voluntary maintenance.

3. FEASIBILITY OF MEETING 1975-1976 STANDARDS IN USE WITH REQUIRED MAINTENANCE

There have been many studies of the effects of maintenance on reducing auto exhaust emissions (4-10, 12-16, 25-28). These studies have shown that there are 10:1 differences among emissions from cars and that the high emitters can be brought down to acceptable levels with proper maintenance.

REDUCTIONS IN EMISSIONS AFTER MAINTENANCE

Results of some of these maintenance programs are shown in Table 15 for pre-controlled models, Table 16 for 1966-1969 models, Table 17 for 1970 models, and Table 18 for 1971 models. Most of the maintenance and surveillance programs have been performed on California cars; hence, the classification of maintenance and surveillance programs has been on the basis of model years according to controls applicable to California.

Because these different maintenance programs have used different test procedures, a list of standards for the various test procedures by model year applicable to California is shown in Table 19. Where emission standards were not available for a particular test procedure, values were derived by proportion among the tests.

These maintenance programs indicate that maintenance can reduce HC emissions over the total fleet by 10-50 percent, and CO by 5-40 percent. Results of these studies also indicate that emission reductions after maintenace depend on three criteria, namely:

1. Extent of maintenance, for example, an idle adjustment only versus complete maintenance.
2. Percent of cars rejected for maintenance.
3. Average level of fleet before maintenance, that is, how dirty the vehicles are to begin with.

Table 15 **Emission Reductions of Pre-Controlled Vehicles after Maintenance**

Program	Ref.	n			HC ppm	% Change	CO %	% Change
B-O CARB 7M 1964	26	50		BTU	892		3.21	
				ATU	840	- 5.8	2.96	- 7.8
		41		BTU	906		3.33	
				ATU	864	- 4.6	3.02	- 9.3
		11		BTU	687		2.74	
				ATU	602	-12.4	2.45	-10.6
		16		BTU	1033		3.00	
				ATU	790	-23.5	3.45	+15.0
		30		BTU	783		3.11	
				ATU	489	-37.5	2.61	-16.1
		30		BTU	917		2.76	
				ATU	638	-30.4	2.31	-16.3
NJ Scott 7MHS 1967	4	97		BTU	748		2.97	
				ATU	557	-25.5	2.17	-26.7
GM Idle Adjust 7MHS 1970	5	213		BTU	719		2.97	
				ATU	655	- 8.9	2.41	-18.9
NJ Clayton 7MHS 1970	6	166		BTU	1049		4.02	
			100% R	ATU	524	-50.0	2.51	-37.4
		166	Keymode	BTU	1049		4.02	
			82.5% R	ATU	535	-49.0	2.69	-33.1
		166	Idle	BTU	1049		4.02	
			71.1% R	ATU	555	-47.1	2.87	-28.6

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Table 15 (continued)

Program	Ref.	n			HC g/mi	% Change	CO g/mi	% Change
NJ REPAIR ACID 1971	7	133		BTU	12.8		123	
				ATU	6.5	-49.2	81	-34.1
Northrop 7MHS 1971	9	95	C-C	BTU	6.56		61.5	
			100% R	ATU	5.93	- 9.6	58.1	- 5.5
		172	Idle	BTU	7.54		71.2	
			53.5% R	ATU	5.35	-29.0	56.4	-20.8
		178	Keymode	BTU	7.49		77.8	
			62.4% R	ATU	5.24	-30.0	49.4	-36.5
		108	Diagnostic	BTU	7.84		69.4	
			100% R	ATU	4.97	-36.6	52.1	-24.9
		74	AAMP	BTU	8.93		78.8	
			100% R	ATU	5.94	-33.5	63.1	-19.9
EPA CVS-75 1971	14		Idle	BTU	6.8		75.7	
			% R NA	ATU	5.8	-14.7	62.0	-18.1
			Idle	BTU	8.4		97.7	
			% R NA	ATU	5.5	-34.5	66.9	-31.5
			Keymode	BTU	7.9		85.5	
			% R NA	ATU	5.6	-29.1	73.4	-14.1
			Keymode	BTU	8.0		88.4	
			% R NA	ATU	4.9	-38.8	61.4	-30.5
TRW CVS-72 1971	10	147		BTU	12.00		131.5	
				ATU	10.84	- 9.6	122.4	- 6.9

Table 16 Emission Reductions of Controlled Vehicles after Maintenance (1966-1969 Models)

Program	Ref.	n			HC ppm	% Change	CO %	% Change
B & R CARB 7MHS 1967	27	12	Simple adjust	BTU	318		1.81	
				ATU	268	-15.7	1.38	-23.8
		10	Engine Diagnosis	BTU	346		2.61	
				ATU	271	-21.7	1.62	-37.9
		86	Total fleet 26% R	BTU	260		1.46	
				ATU	244	- 6.2	1.27	-13.0
NJ Scott 7MHS 1967	4	68		BTU	309		1.83	
				ATU	270	-12.5	1.28	-30.0
GM Idle Adjust 7MHS 1970	5	228		BTU	306		1.49	
				ATU	285	- 6.9	1.12	-24.8
NJ Clayton 7MHS 1970	6	35	Total fleet 100% R	BTU	696		2.64	
				ATU	270	-61.2	1.23	-53.2
		30	Keymode 100% R	BTU	696		2.64	
				ATU	270	-61.2	1.23	-53.2
		33	Idle 94.3% R	BTU	696		2.64	
				ATU	345	-50.5	1.30	-50.8
					g/mi		g/mi	
NJ REPAIR ACID 1971	7	48		BTU	7.5		99	
				ATU	5.4	-28.0	52	-47.5

Table 16 (continued)

Program	Ref	n			HC g/mi	% Change	CO g/mi	% Change
Northrop 7MHS 1971	9	128	Idle	BTU	2.99		37.7	
			33.6% R	ATU	2.47	-17.4	27.9	-26.0
		122	Keymode	BTU	3.45		35.0	
			35.2% R	ATU	2.49	-27.8	24.3	-30.6
		89	Diagnostic	BTU	3.10		34.7	
				ATU	2.59	-16.5	26.7	-23.1
		61	C-C	BTU	3.74		35.2	
				ATU	2.80	-25.3	33.4	- 5.1
		36	AAMP	BTU	4.53		43.8	
				ATU	3.21	-29.2	38.8	-11.4
EPA CVS-75 1971	14		Idle	BTU	4.4		53.1	
			% R NA	ATU	3.4	-22.7	47.6	-10.4
			Idle	BTU	5.2		62.6	
			% R NA	ATU	3.8	-26.9	48.8	-22.0
			Keymode	BTU	4.4		60.1	
			% R NA	ATU	3.5	-20.5	49.7	-17.3
			Keymode	BTU	4.3		49.4	
			% R NA	ATU	3.2	-25.6	33.8	-31.6
TRW CVS-72 1971	10	118		BTU	7.3		85.7	
				ATU	6.5	-11.2	82.0	- 4.3

Table 17 Emission Reductions of Controlled Vehicles after Maintenance (1970 Models)

Program	Ref.	n			HC g/mi	% Change	CO g/mi	% Change
NJ REPAIR ACID 1971	7	11		BTU	4.4		82	
				ATU	2.9	-34.1	31	-62.2
Northrop 7MHS 1971	9	17	C-C	BTU	1.92		29.75	
				ATU	2.00	+ 4.2	27.45	- 7.8
		15	AAMP	BTU	1.97		28.03	
				ATU	2.11	+ 7.1	23.31	-16.8
TRW CVS72 1971	10	32		BTU	6.95		91.04	
				ATU	5.26	-24.3	75.22	-17.4

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Table 18 Emission Reductions of Controlled Vehicles after Maintenance (1971 Models)

Program	Ref.	n			HC g/mi	% Change	CO g/mi	% Change	NO_x g/mi	% Change
TRW CVS72 1971	10	150	8059 mi	BTU	4.44		63.4		5.95	
				ATU	4.38	- 1.4	57.8	- 8.9	5.80	- 2.5
GM 7MCS 1972	16	127	EOL	BTU	1.25		12.89		2.70	
				ATU	1.11	-11.2	11.98	- 7.1	2.70	0.0
		127	4332 mi	BTU	1.59[a]		22.09		2.85	
				ATU	1.12	-29.6	15.70	-28.9	2.70	- 5.3
		86	6448 mi	BTU	1.46		19.46		2.78	
				ATU	1.19	-18.5	16.00	-17.7	2.74	- 1.4
		77	10,405 mi	BTU	1.41		18.38		2.74	
				ATU	1.18	-16.3	16.69	- 9.2	2.76	+ 0.1
		26	14,558 mi	BTU	1.33		18.85		2.79	
				ATU	1.14	-14.3	16.68	-11.5	2.82	+ 1.1
CARB[b] 7MHS 1971-72	2	43	2380 mi	BTU	1.69		11.93		3.01	
		88	6555 mi	BTU	1.79		13.73		3.25	

[a] Does not include emissions from two card with plug wires off (estimate would be 1.88).

[b] Surveillance without maintenance.

Table 19 Test Conversions for Emission Standards Applicable to California

Model Year		Open, 7MHS		Closed, 7MHS	Open, 7MCS		1972 CVS	1975 CVS
Pre-cont. 1966	HC	(773)	10.0	15.5	(850)	11.		
	CO	(2.76)	66.	93.	(3.4)	80.		
	NO$_x$			3.7	(1000)	4.		
1966-1969	HC	(250)	3.1	4.9	(275)	3.4	7.1	
	CO	(1.22)	28.1	51.	(1.5)	35.	69.	
	NO$_x$				(1000-1500)	4-6	6.0	
1970	HC	(150)	1.8	3.3	(175)	2.2	4.6	4.1
	CO	(0.8)	19.	31.	(0.96)	23.	47.	34.
	NO$_x$		4.1	5.9	(1500)	4-6	6.0	[6.2
1971	HC		1.8	3.3	(175)	2.2	4.6	4.1
	CO		19.	31.	(0.96)	23.	47.	34.
	NO$_x$		4.1	5.9	(1000)	4.0	6.0	4-6.2
1972	HC		1.4		(125)	1.5	3.2	2.9
	CO		16.1		(1.0)	19.5	39.	28.
	NO$_x$		3.1		(800)	3.0	4.5	4.7
1973	HC		1.4			1.5	3.2	2.9
	CO		16.1			19.5	39.	28.
	NO$_x$		2.1			2.0	3.0	3.1
1974	HC		1.4			1.5	3.2	2.9
	CO		16.1			19.5	39.	28.
	NO$_x$		1.4			1.3	2.0	2.1
1975-1976	HC		0.21			0.22	0.46	0.41
	CO		1.97			2.4	4.8	3.4
	NO$_x$		0.27			0.26	0.4	0.4

Values of HC and NO$_x$ in parentheses are in ppm.
Values of CO in parentheses are as %.
All other values are as g/mi.
Brackets indicate no legislated standards.

Extent of Maintenance

How extent of maintenance affects emission reductions is best illustrated by comparing the New Jersey complete maintenance program (4) with the GM idle adjustment program (5). The GM idle adjustment program consisted of setting only the idle speed and mixture. Ignition timing was not reset, nor were any spark plugs replaced. Both fleets were relatively close in average levels of emissions before maintenance, and the data are shown below.

EFFECT OF EXTENT OF MAINTENANCE ON EMISSION REDUCTIONS

Program		HC ppm	% Change	CO %	% Change
Pre-controlled, no standards					
NJ	BTU	748		2.97	
Complete maintenance 7MHS	ATU	557	- 25.5	2.17	- 26.7
GM	BTU	719		2.97	
Idle Adjustment 7MHS	ATU	655	- 8.9	2.41	- 18.9
Controlled, standards		250		1.22	
NJ	BTU	309		1.83	
Complete maintenance 7MHS	ATU	270	- 12.5	1.28	- 30.0
GM	BTU	306		1.49	
Idle adjustment 7MHS	ATU	285	- 6.9	1.12	- 24.8

As shown above, percent reductions of HC and CO emissions after tune-up (ATU) are much less for the simple idle adjustment than for the complete maintenance program.

It should be noted that in some of the maintenance studies the maintenance was done by mechanics at garages, dealerships, etc., while in other programs the maintenance was done by research engineers.

Reductions achieved after maintenance in these studies do not show that the reductions achieved by the research engineers are greater than reductions achieved by mechanics available to the public, with the exception of the Frank study (16) where a vehicle was not returned to the owner until the vehicle did meet standards. However, this study was carried out on vehicles up to only one year old.

Percent Rejected

The effect of percent rejected for maintenance on reduction in emissions after maintenance is illustrated by two Northrop programs (9), namely the C-C (Certificate of Compliance) and the AAMP (Annual Adjustment and Maintenance Program), and again the New Jersey (4) and GM (5) programs. Percent HC reduction over the total fleet is plotted in Figure 5 against percent of vehicles sent for repair for each of these four programs. Rejection for repair is on the basis of 7MHS emissions of HC and CO. Note that the relationship is nonlinear. That is, the bulk of the HC reduction after maintenance is accomplished in rejecting the high emitters, or approximately 30 percent of vehicles. A plateau is reached where further rejection yields either the same reduction, marginal reductions, or even less reduction as 100 percent rejection is approached.

A similar nonlinear relationship is found for CO reductions after maintenance, as shown in Figure 6. In Figure 6, the CO reduction versus percent rejected for the C-C program takes a large dip in percent reduction near 28 percent rejection. This major change in the shape of the curve was caused by emissions from just one vehicle, whose high CO emissions before maintenance were 62.4 g/mi and after-maintenance emissions were 224 g/mi. This emphasizes the importance of proper maintenance and reinspection of work to make sure it was done properly.

There are several reasons for nonlinearity of reduction versus percent rejected. First, mechanics have never been known to bring the distributions of HC, CO, and NO_x emissions of vehicles in use below

FIGURE 5 RELATIONSHIP BETWEEN PERCENT REDUCTION IN HC AND PERCENT REJECTED FOR REPAIR

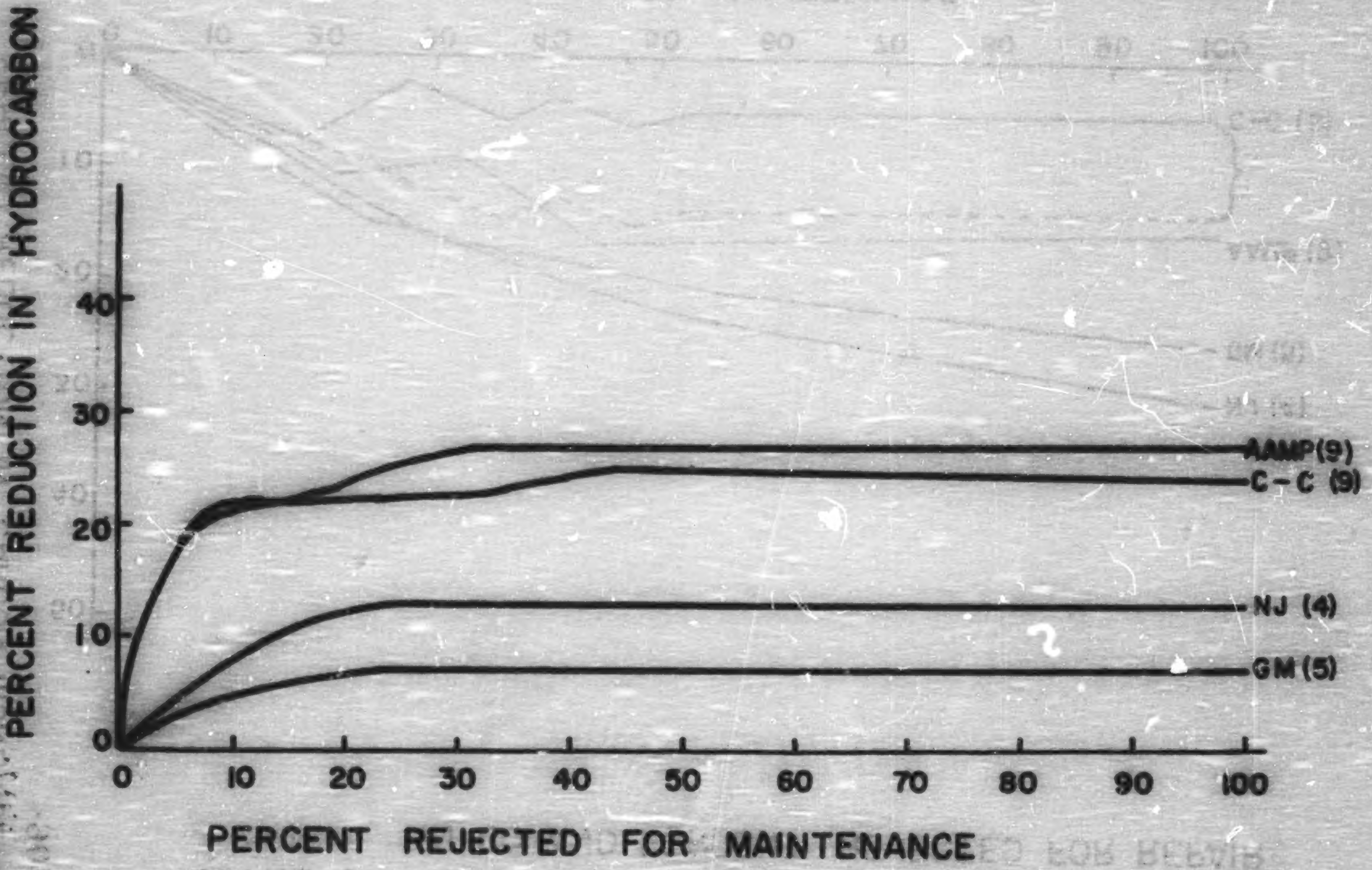
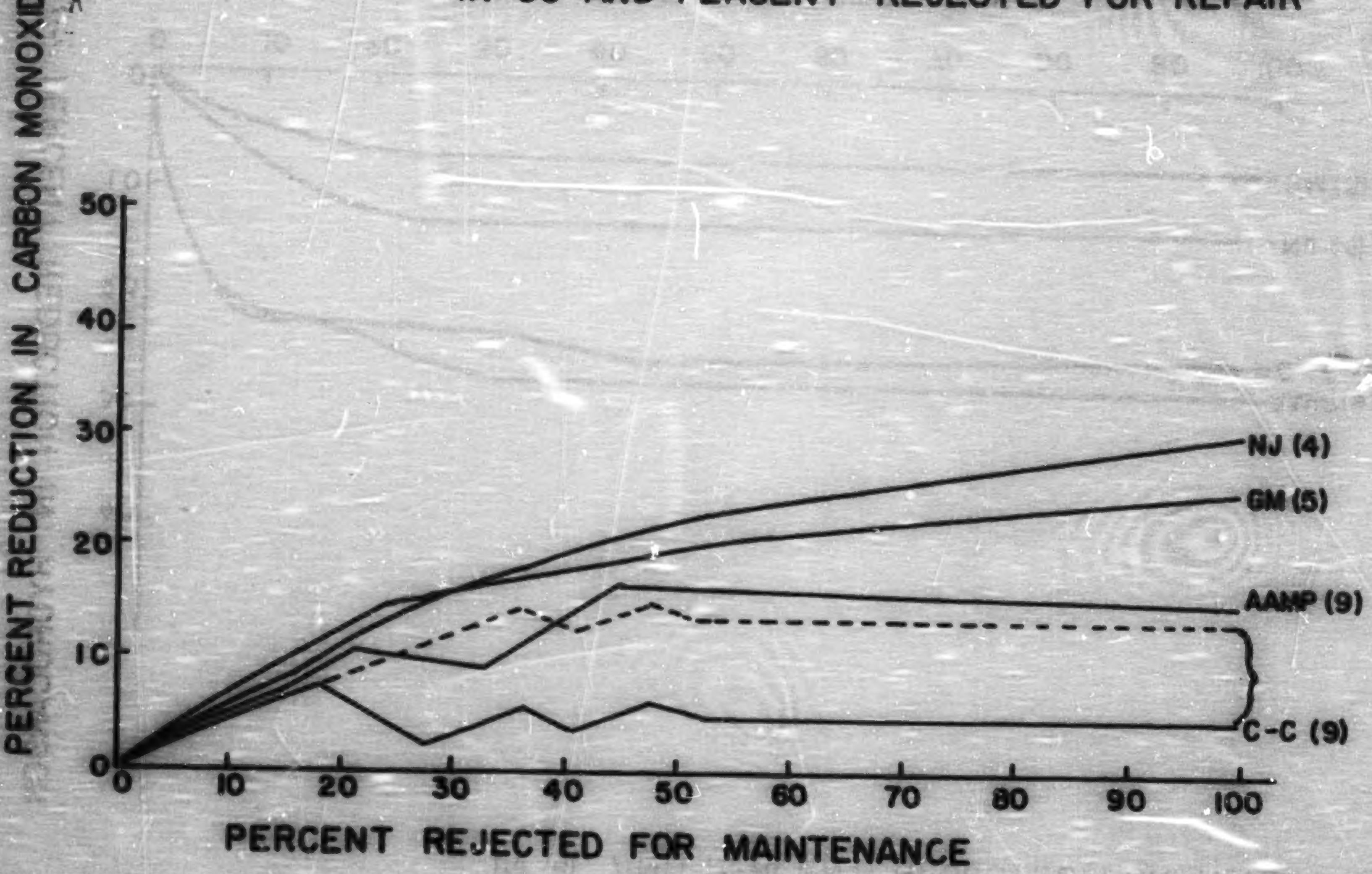


FIGURE 6 RELATIONSHIP BETWEEN PERCENT REDUCTION IN CO AND PERCENT REJECTED FOR REPAIR



the original distributions of emissions found at production. In Figures 7-16 increase or decrease in HC emissions after maintenance is plotted against HC emissions before maintenance. Appropriate standards are indicated by the vertical dashed lines. It is evident from these maintenance programs that maintenance of cars with acceptable levels of emissions have a 50:50 chance of having increased emissions after maintenance. Maintenance of the high emitters does reduce emission levels of the total fleet, whereas maintenance of the acceptable cars does not lower emissions further.

In Figure 10, the dotted lines represent the standard deviation of the 7MHS test for HC, and one readily concludes that increases in emissions are not due to testing variability but to the maintenance. Similarly, increases and decreases in CO after maintenance are shown in Figures 17-26. The standard deviation of the 7MHS test for CO is shown by the dashed lines in Figure 20, and again we can conclude that increases after maintenance are due to the maintenance, not to test repeatability. In all of these programs, there are certain levels of HC and CO above which the vehicles (high emitters) have a high probability of having only decreased emissions after maintenance. This has led to a flurry of attempts at developing short inspection tests to sort the high emitters from the vehicles with acceptable emissions in order to avoid needless maintenance.

Although the Northrop study recommends no reinspection after maintenance, their own data for the C-C program, shown in Figures 11 and 21, illustrate the need for reinspection. Referring to CO reduction versus rejection in Figure 6, the dip in the C-C curve at 28 percent rejected was caused by the vehicle with 224 g/mi CO after maintenance. If this malfunctioning vehicle had been properly maintained, the curve would have continued on, as indicated by the dashed curve, to 10 percent reduction in CO over the total fleet, rather than the 5 percent reduction that was actually obtained.

FIGURE 7 CHANGE IN HC EMISSIONS AFTER MAINTENANCE

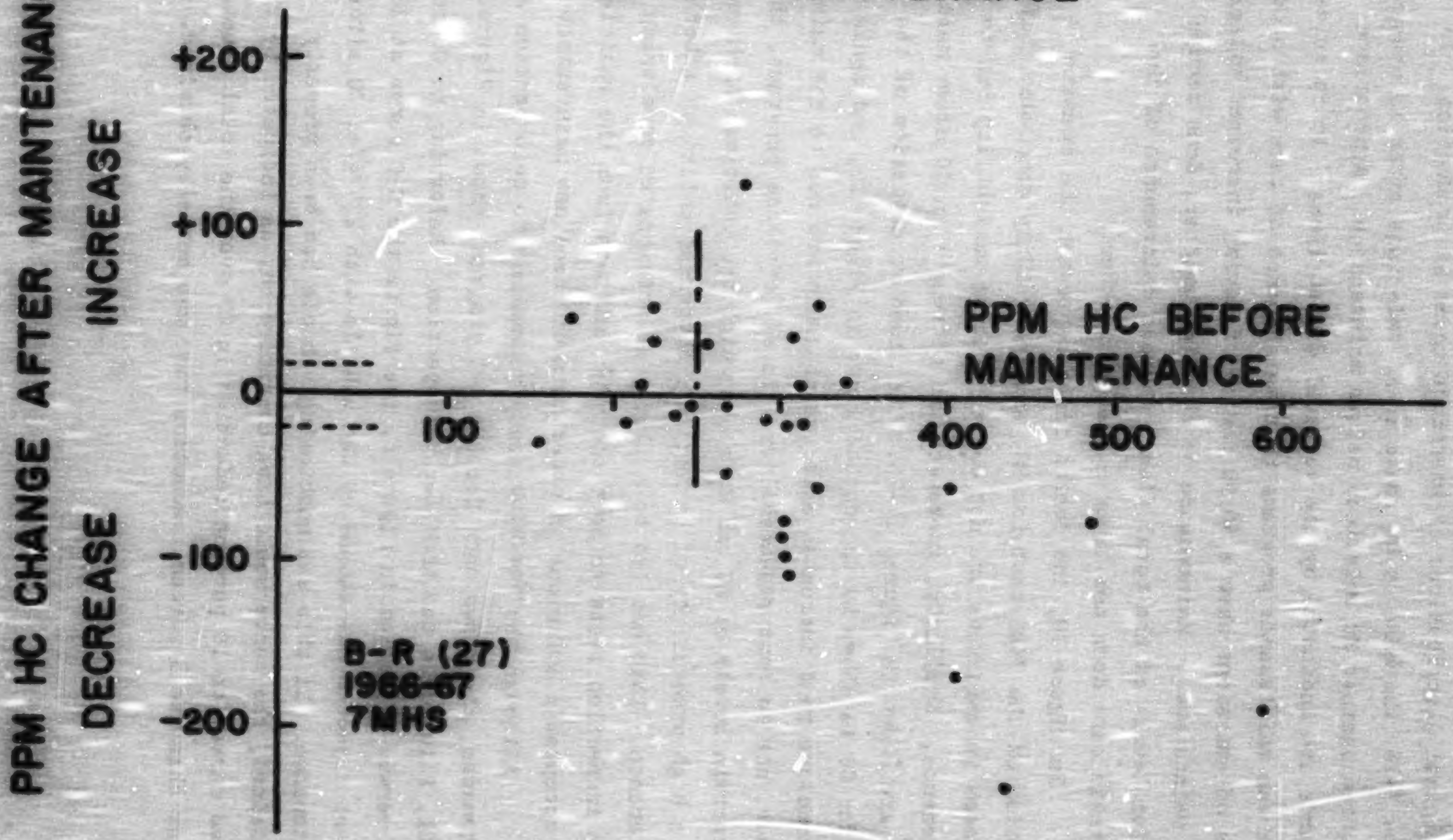


FIGURE 8 CHANGE IN HC EMISSIONS AFTER MAINTENANCE

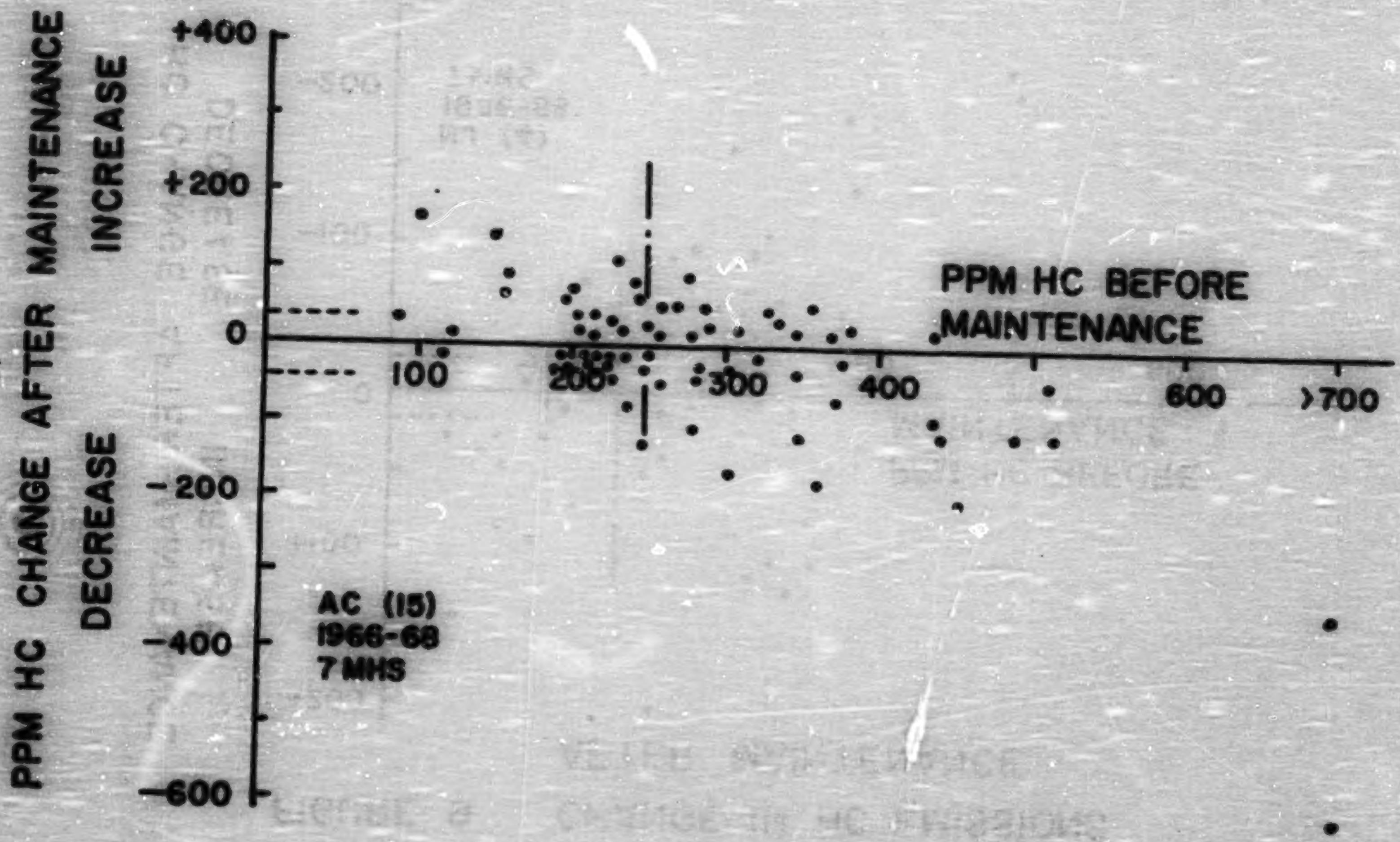


FIGURE 9 CHANGE IN HC EMISSIONS AFTER MAINTENANCE

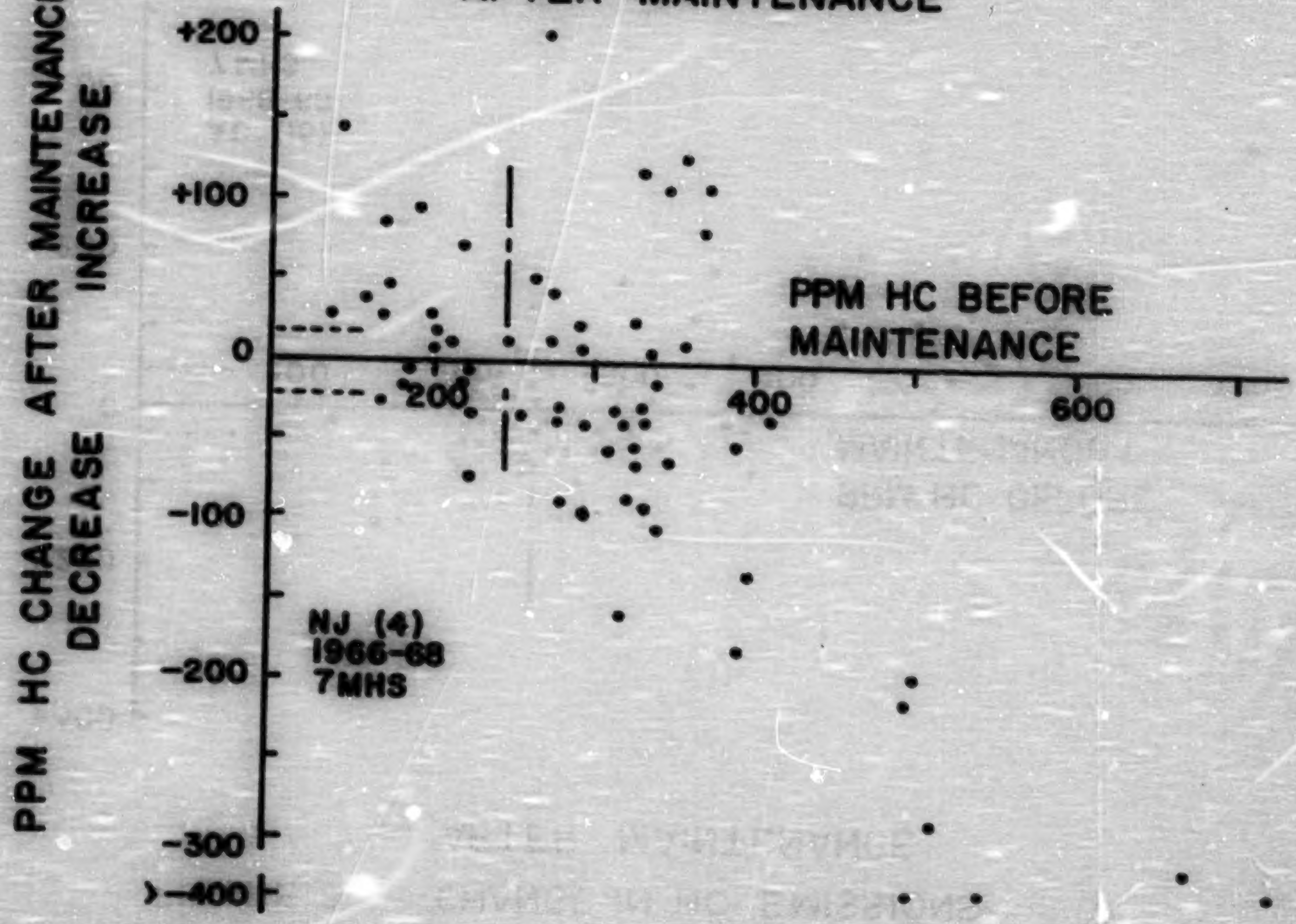


FIGURE 10 CHANGE IN HC AFTER MAINTENANCE

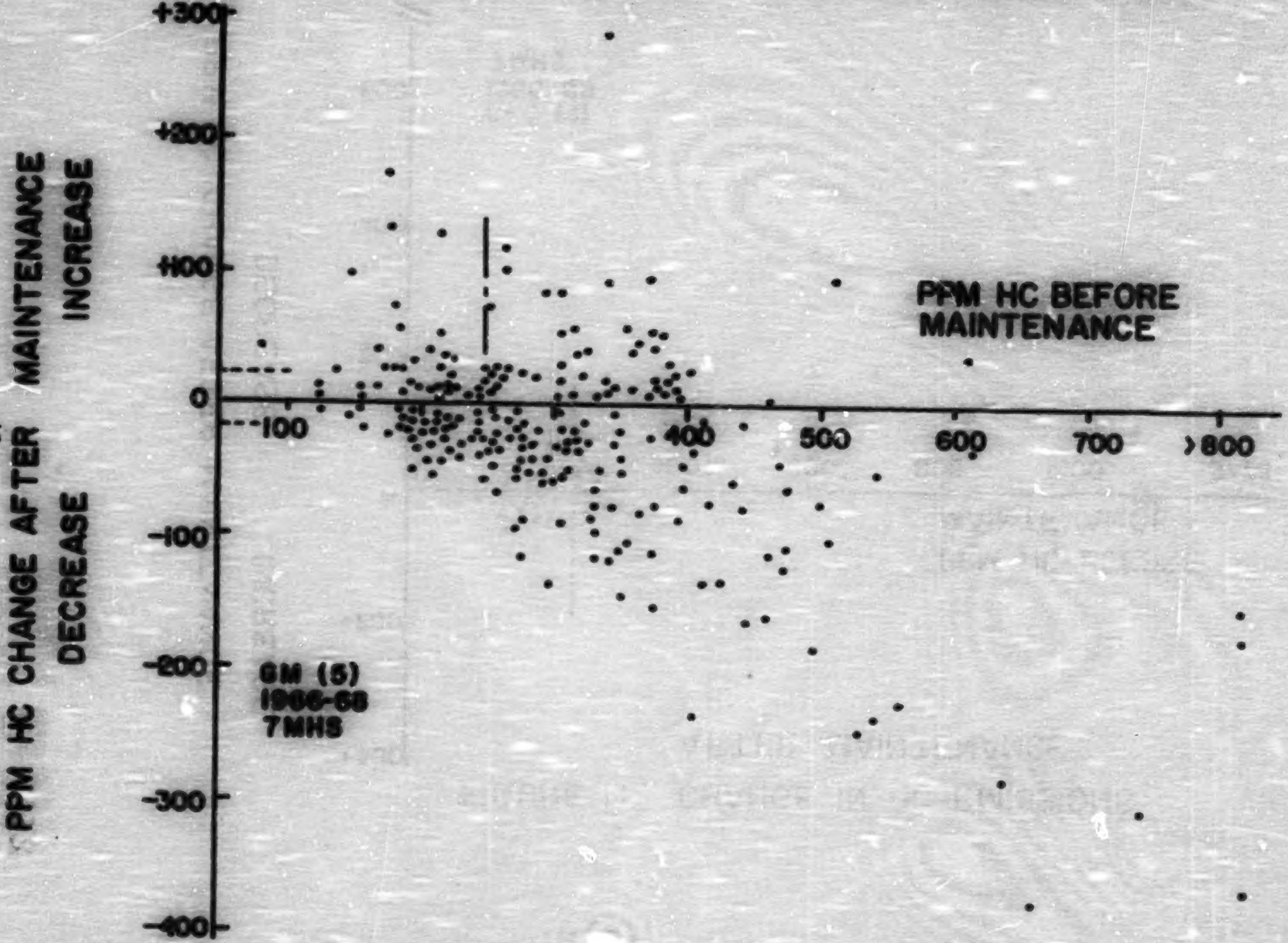


FIGURE 11 CHANGE IN HC EMISSIONS AFTER MAINTENANCE

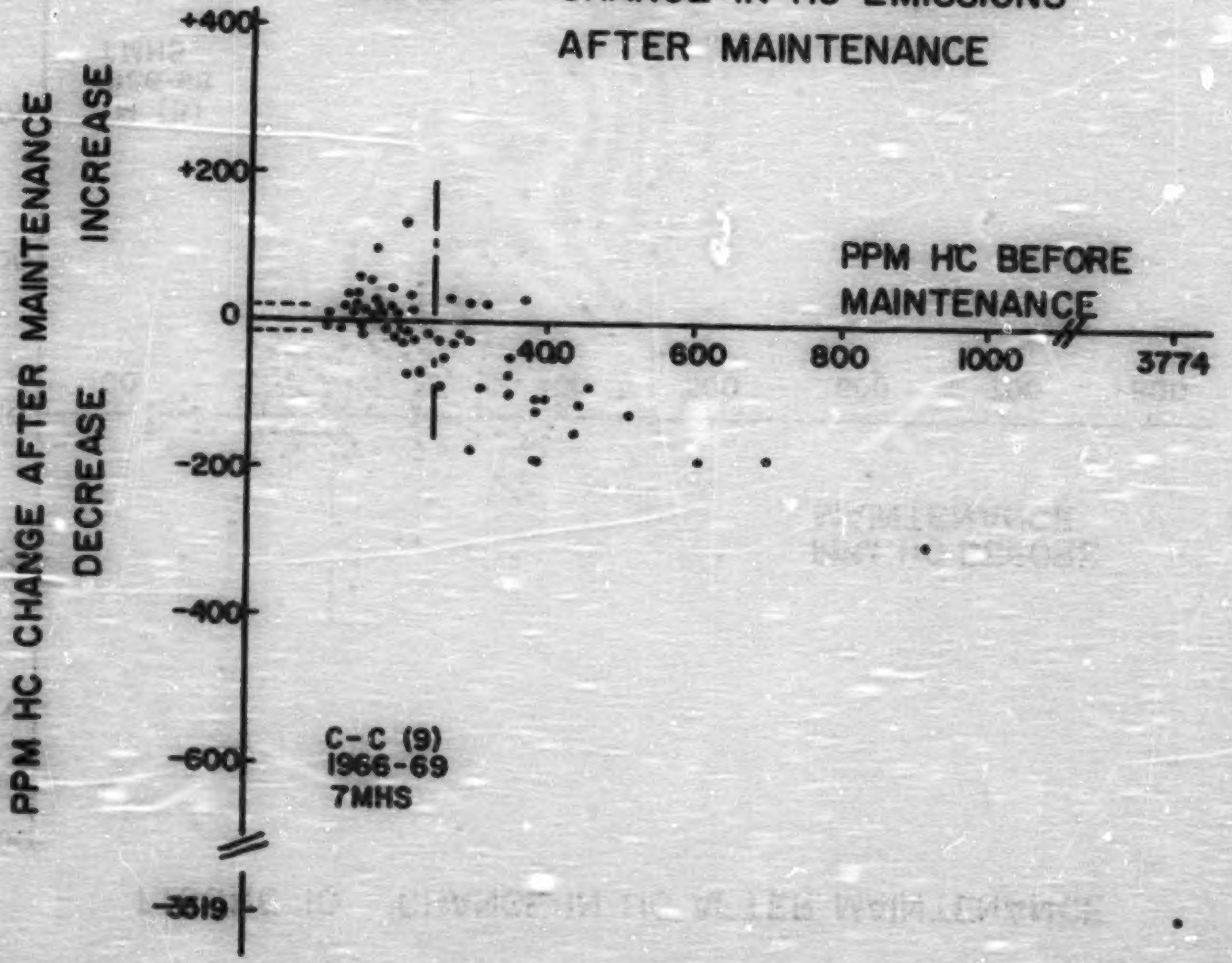


FIGURE 12 CHANGE IN HC EMISSIONS AFTER MAINTENANCE

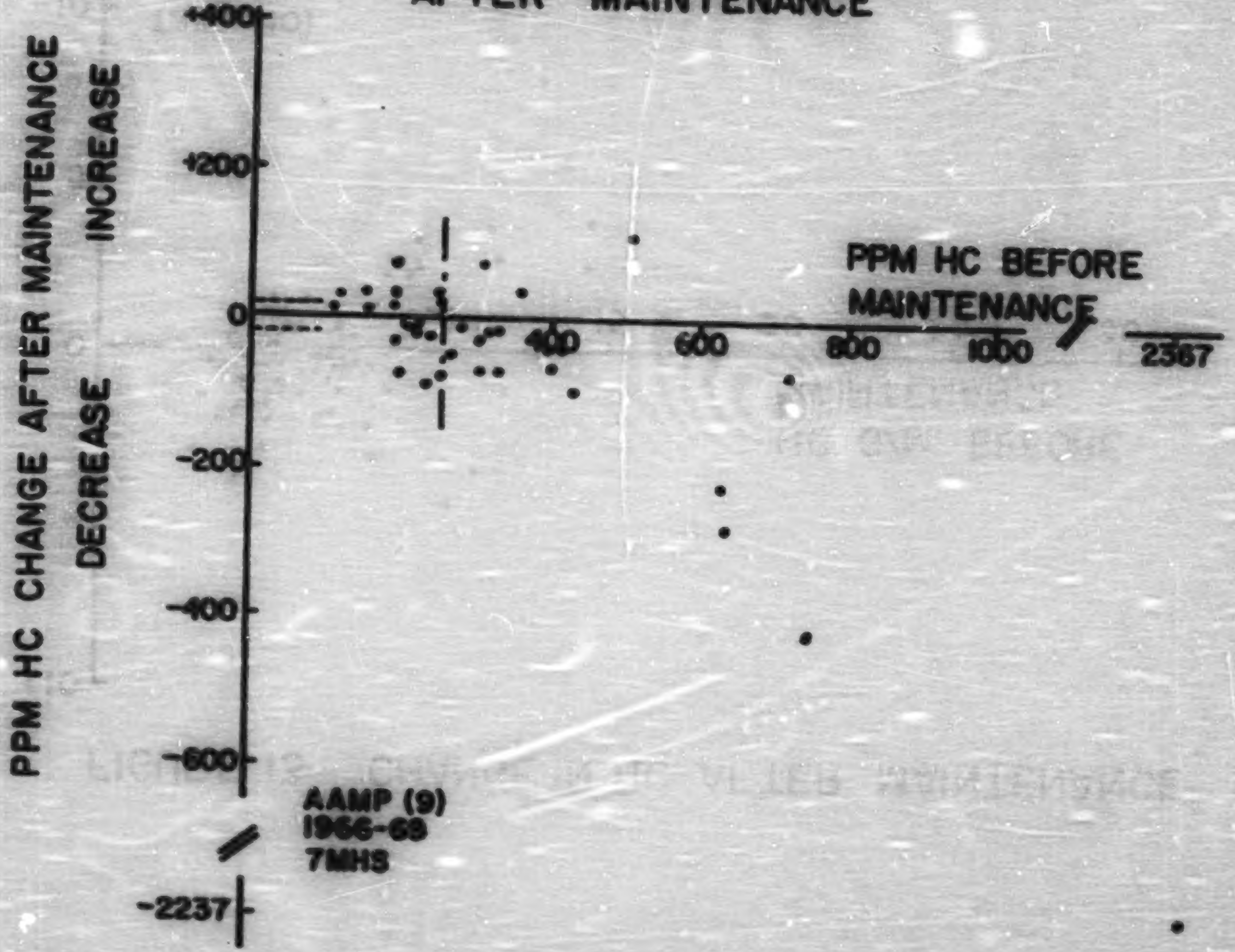


FIGURE 13 CHANGE IN HC AFTER MAINTENANCE

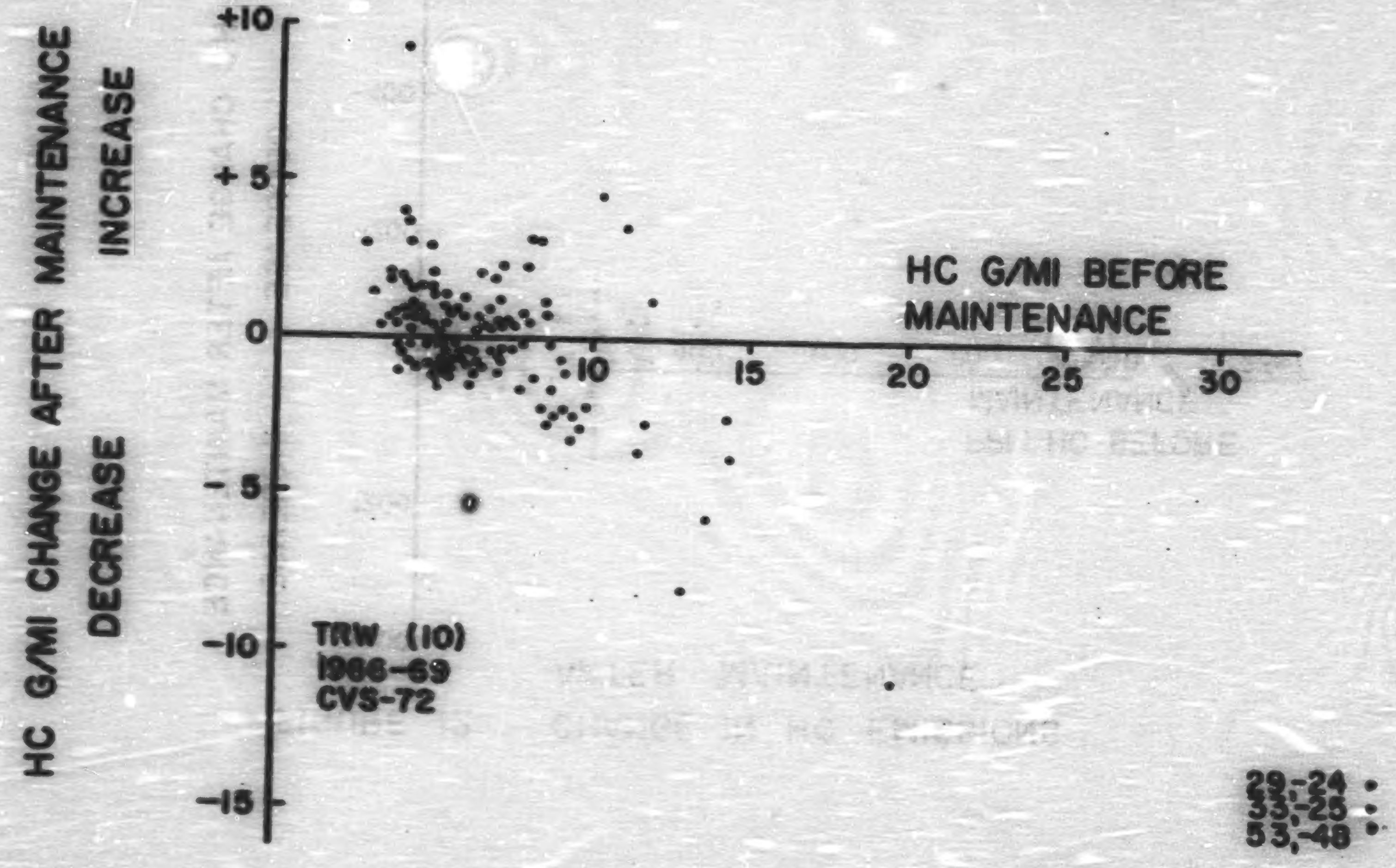


FIGURE 14 CHANGE IN HC EMISSIONS AFTER MAINTENANCE

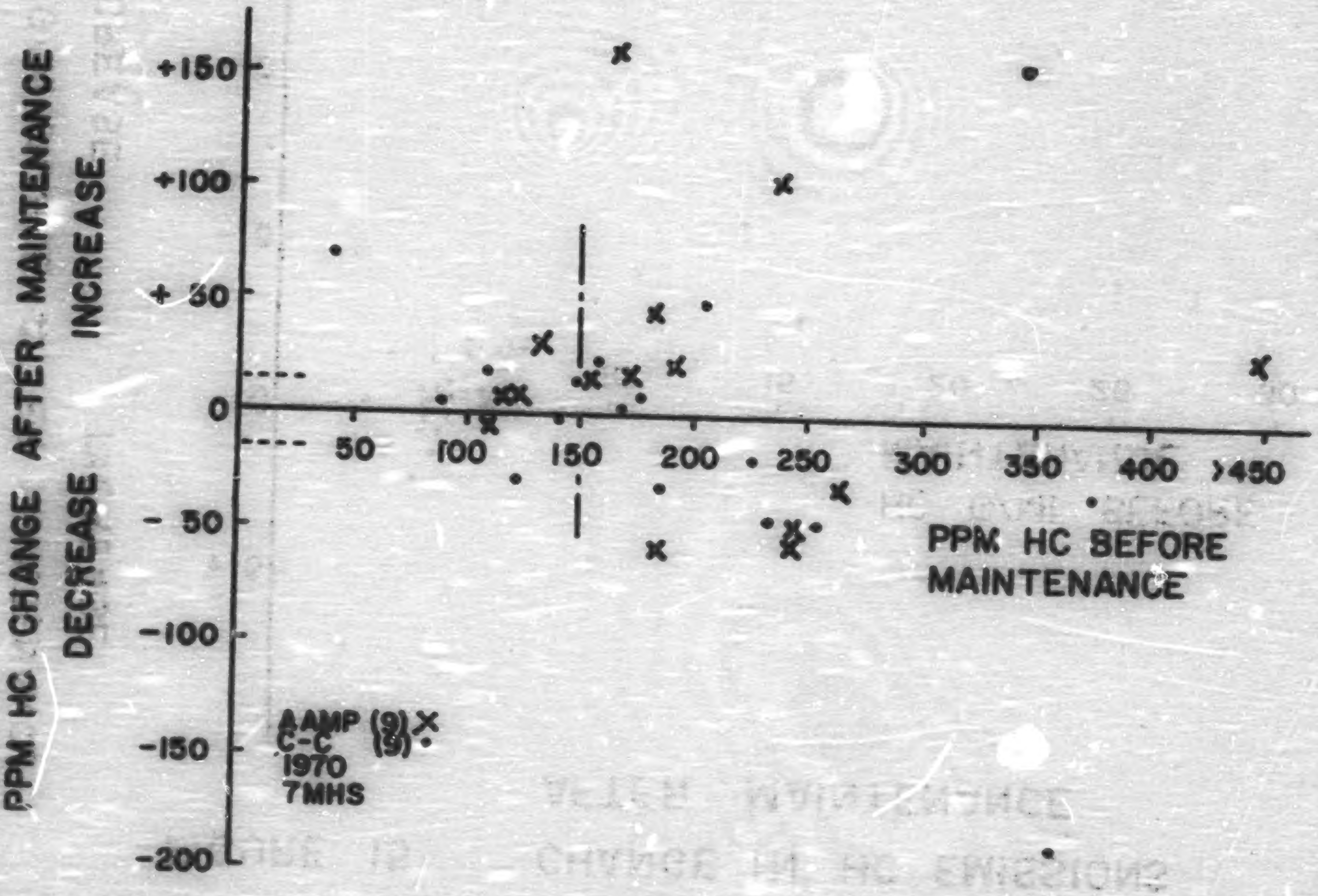


FIGURE 15 CHANGE IN HC EMISSIONS AFTER MAINTENANCE

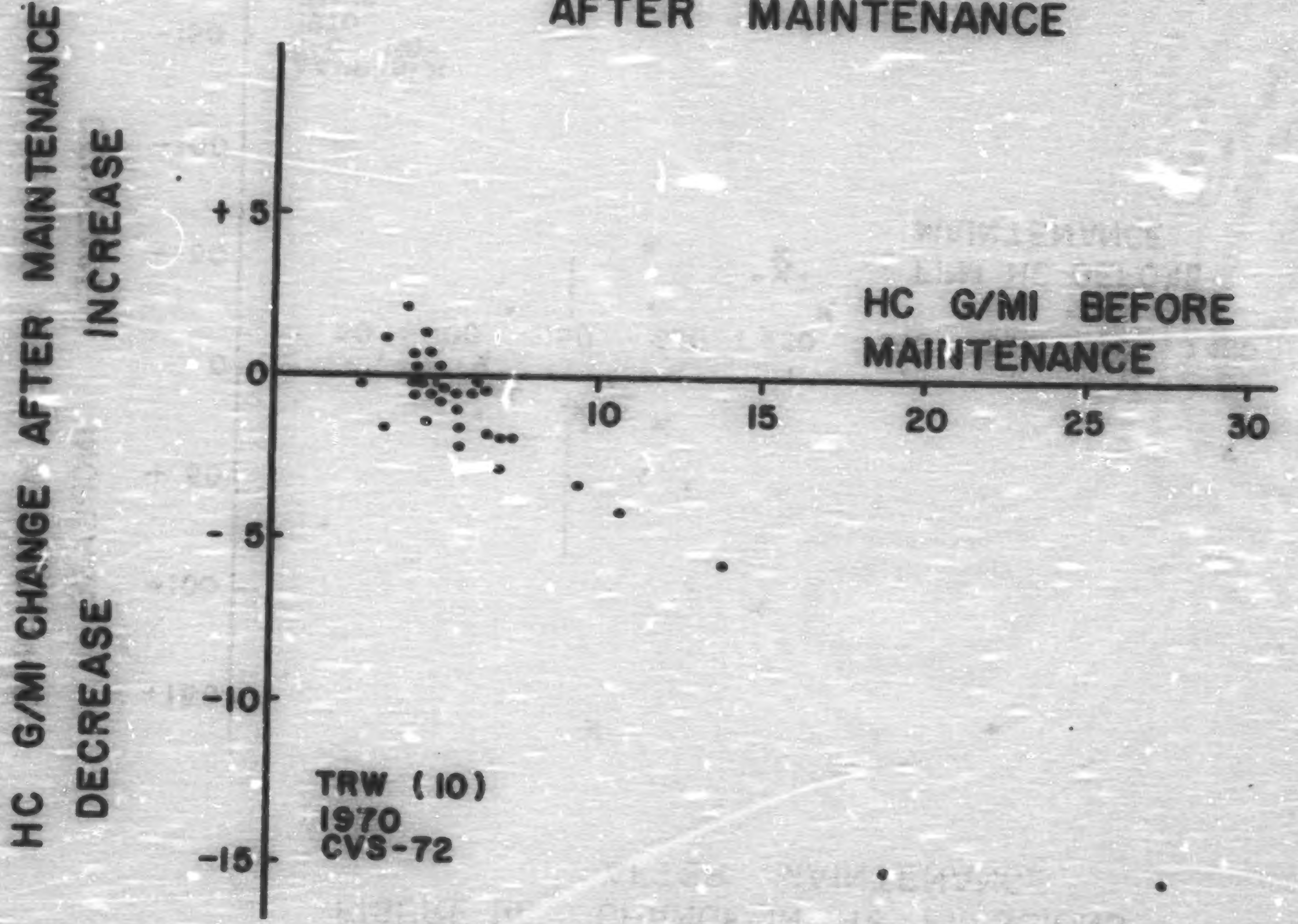


FIGURE 16 CHANGE IN HC AFTER MAINTENANCE

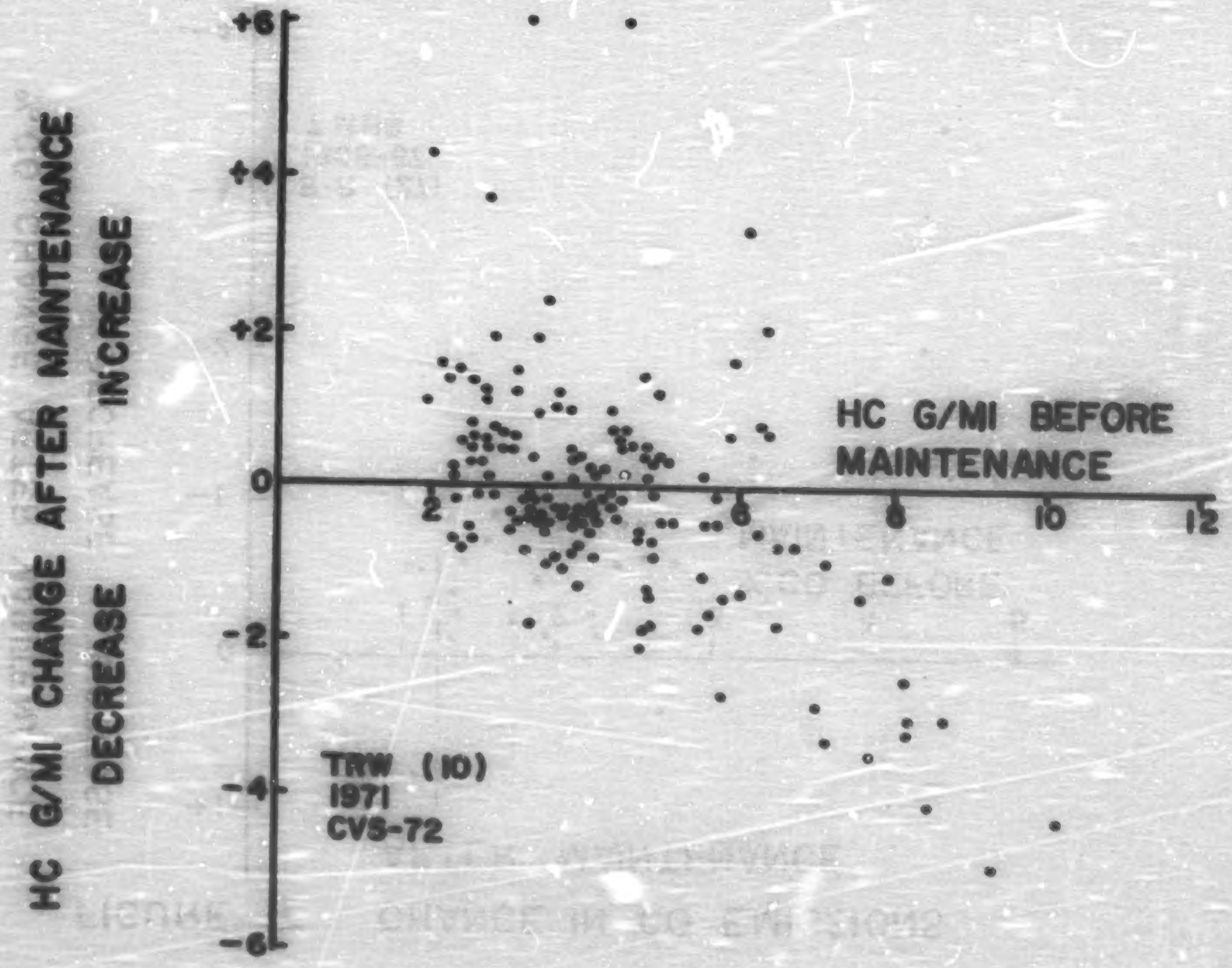


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FIGURE 17 CHANGE IN CO EMISSIONS AFTER MAINTENANCE

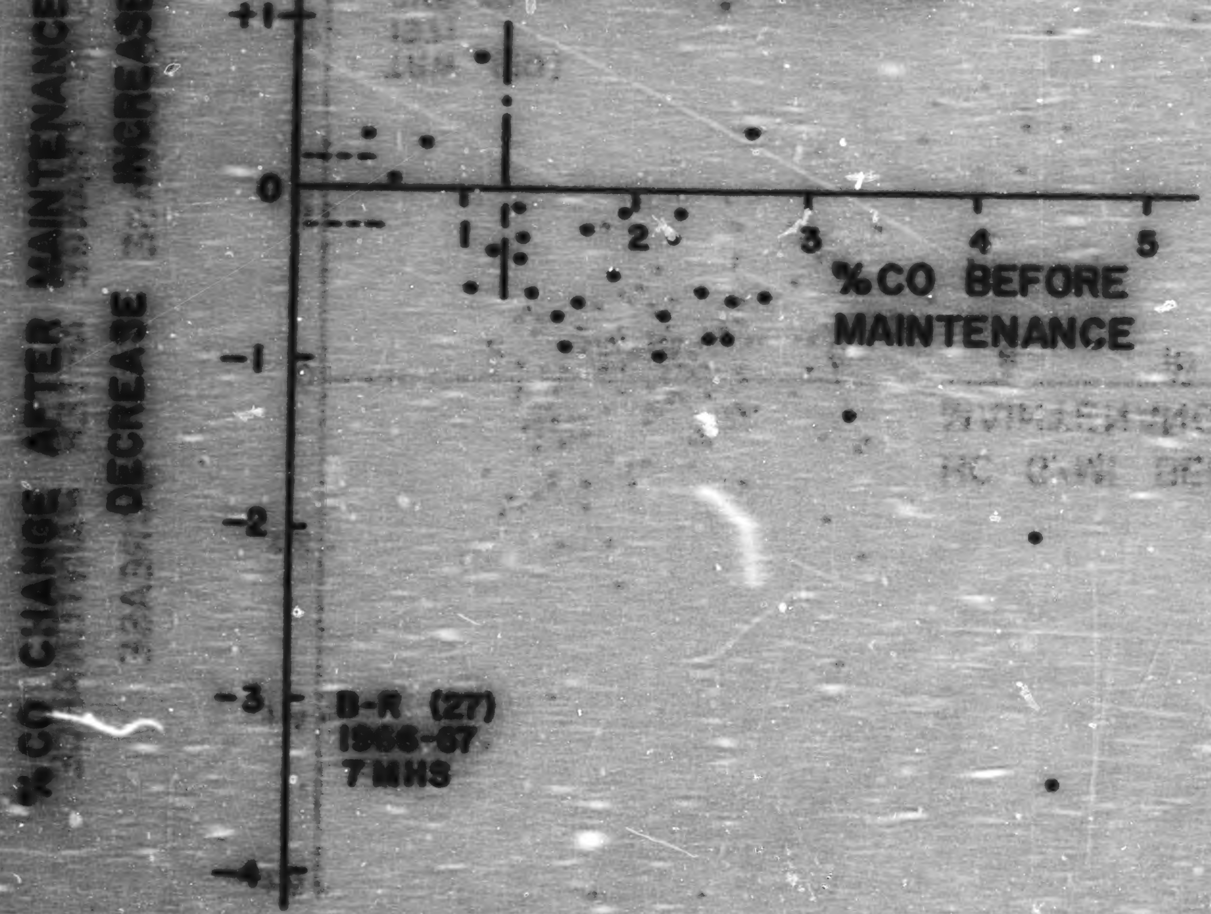

FIGURE 18 CHANGE IN EMISSIONS OF CO AFTER MAINTENANCE

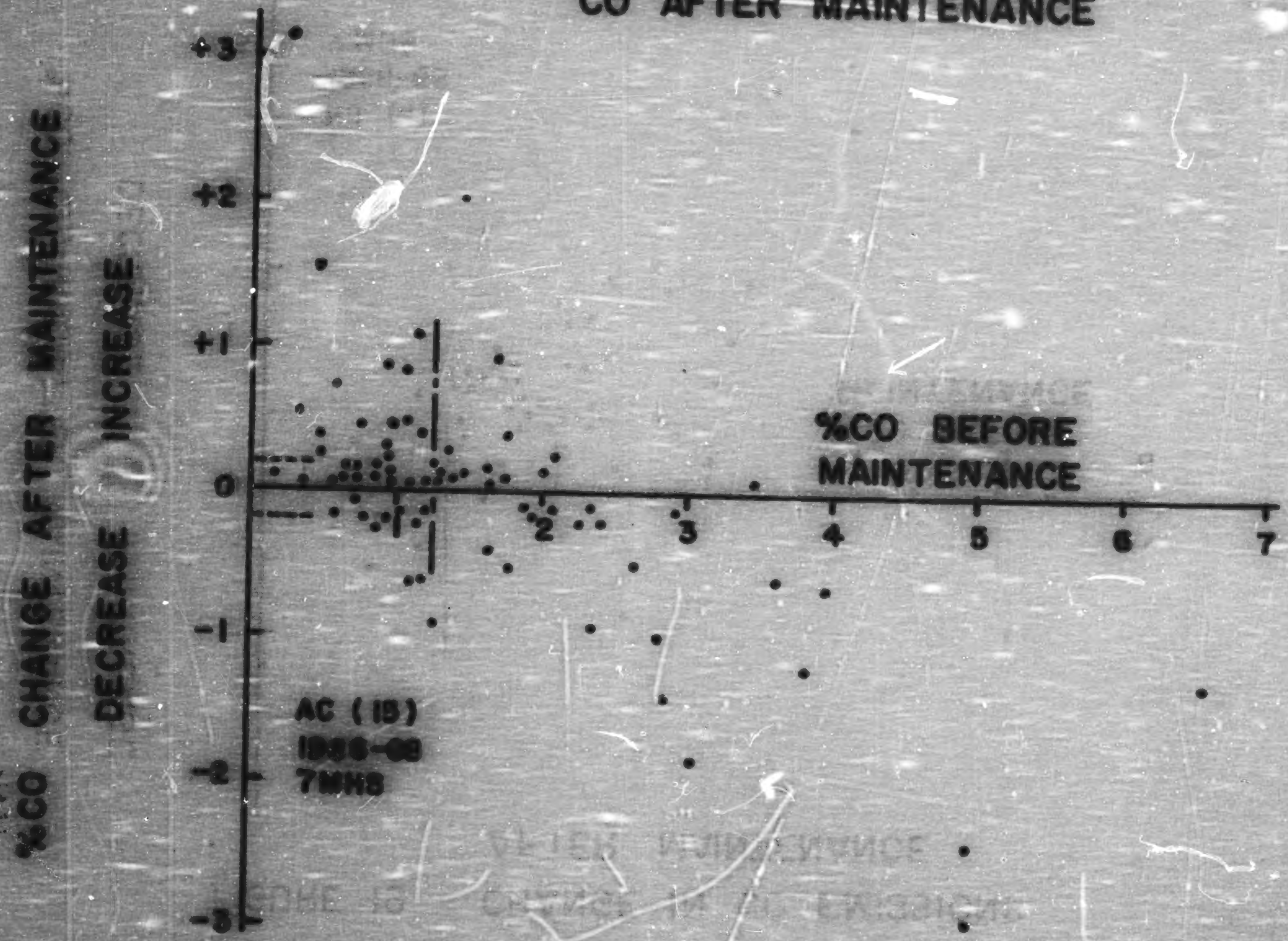

FIGURE 19 CHANGE IN CO EMISSIONS AFTER MAINTENANCE

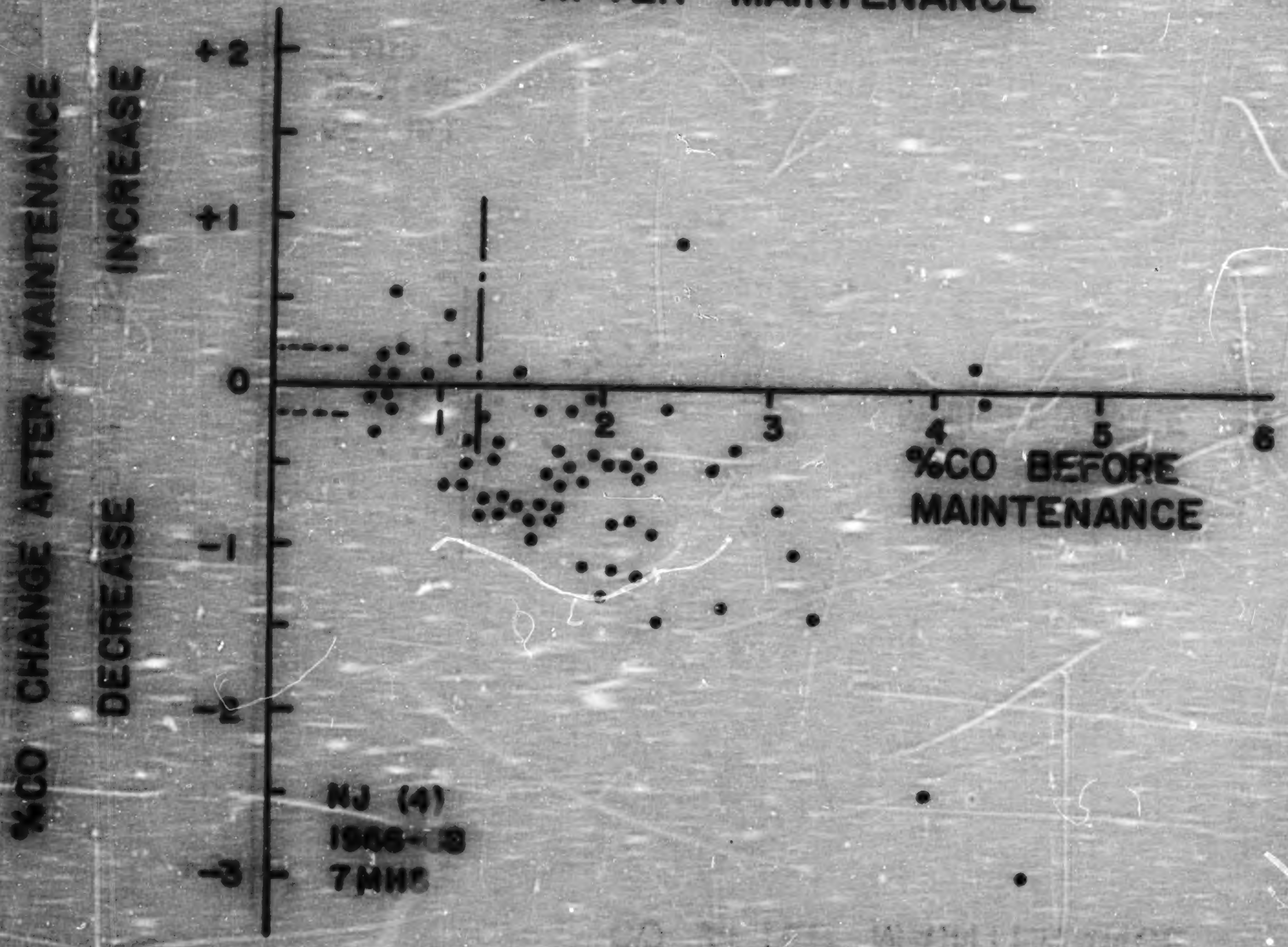

FIGURE 20 CHANGE IN CO EMISSIONS AFTER MAINTENANCE

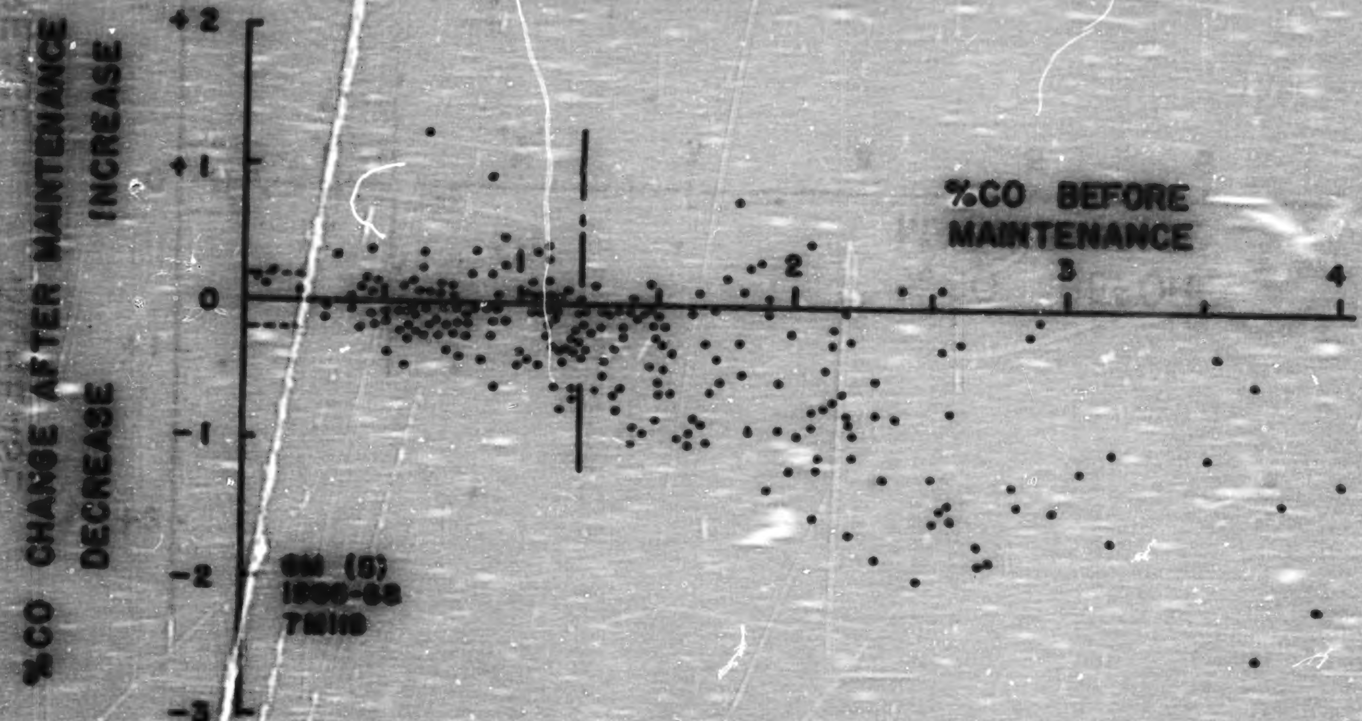

FIGURE 21 CHANGE IN CO EMISSIONS AFTER MAINTENANCE

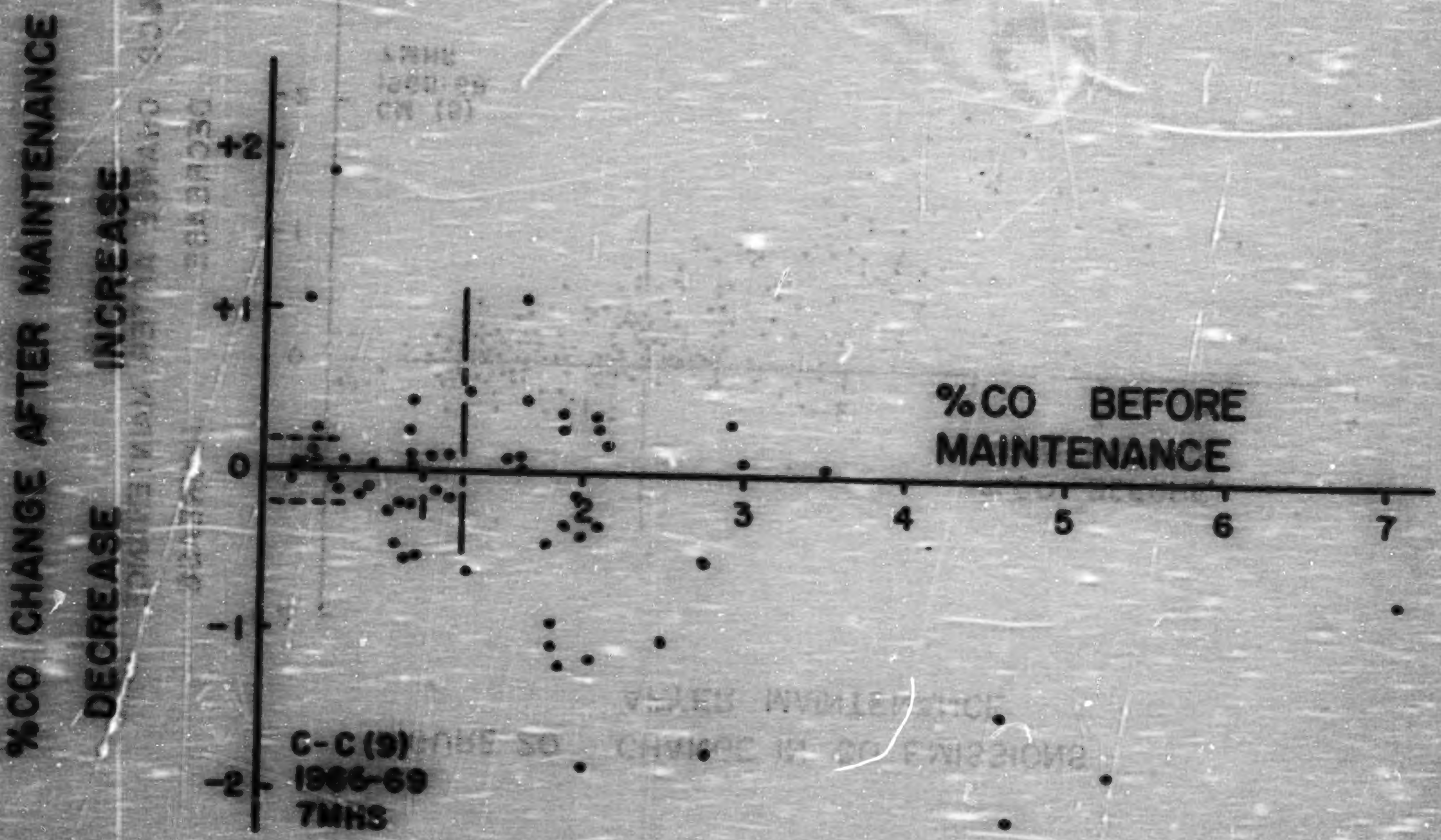

FIGURE 22 CHANGE IN EMISSIONS OF CO AFTER MAINTENANCE

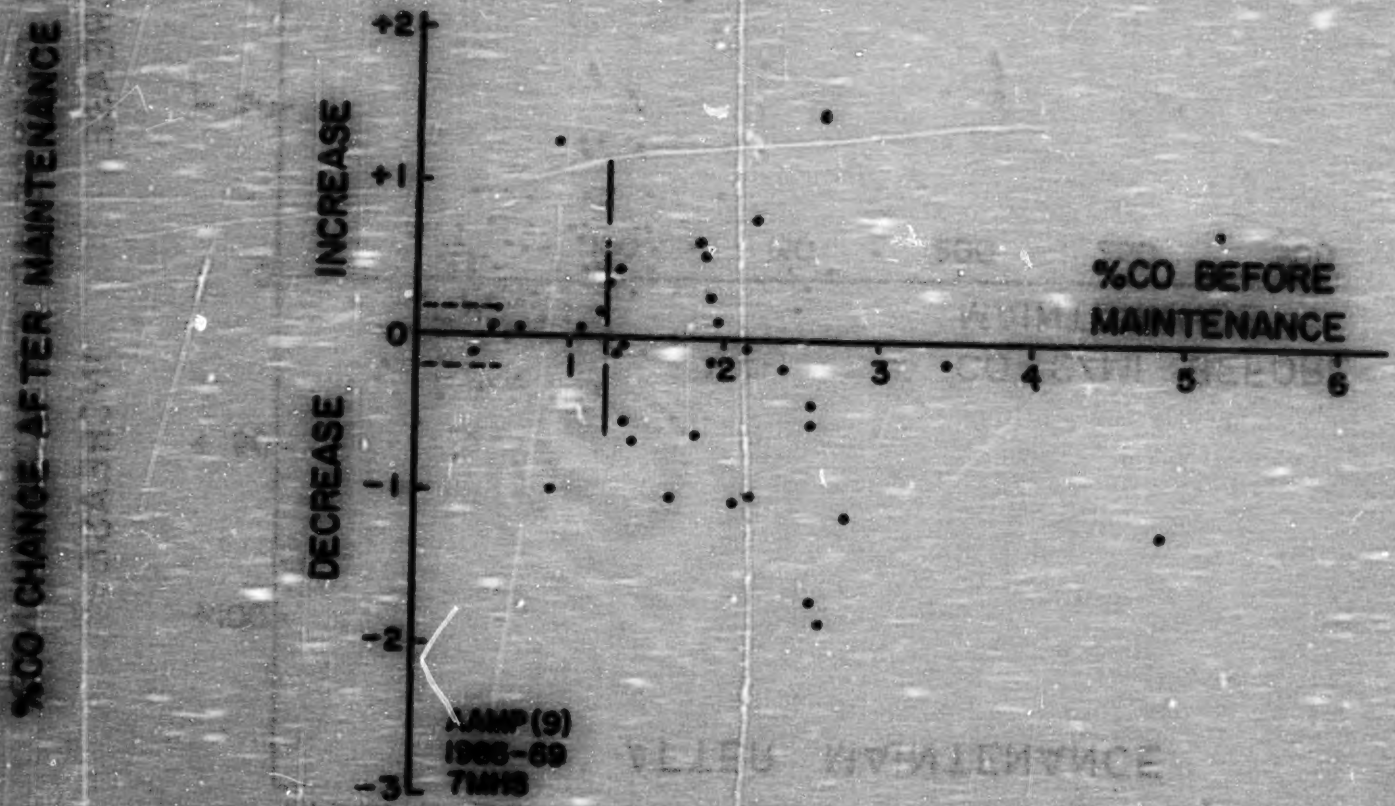

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FIGURE 23 CHANGE IN CO EMISSIONS AFTER MAINTENANCE

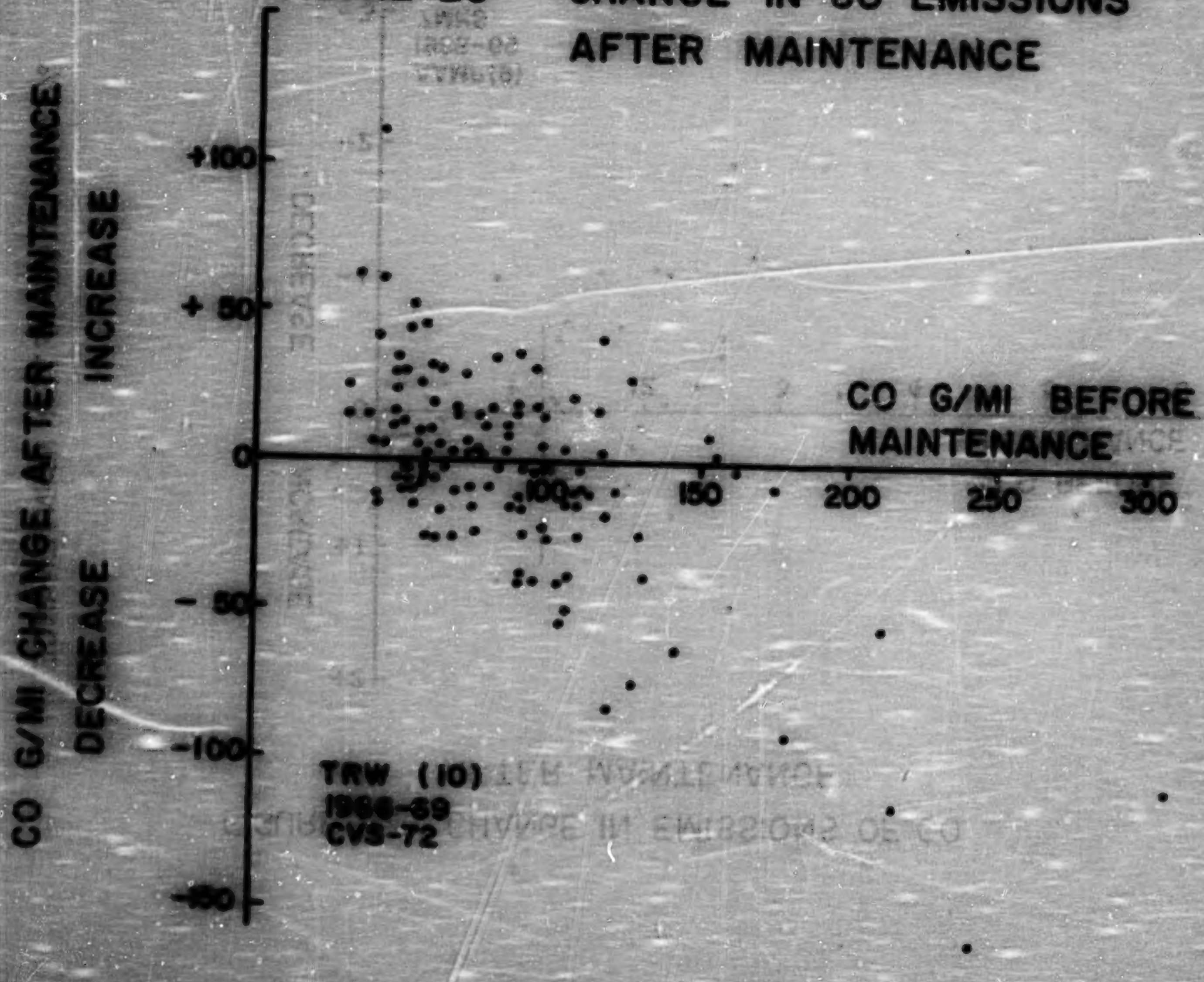


FIGURE 24 CHANGE IN CO EMISSIONS AFTER MAINTENANCE

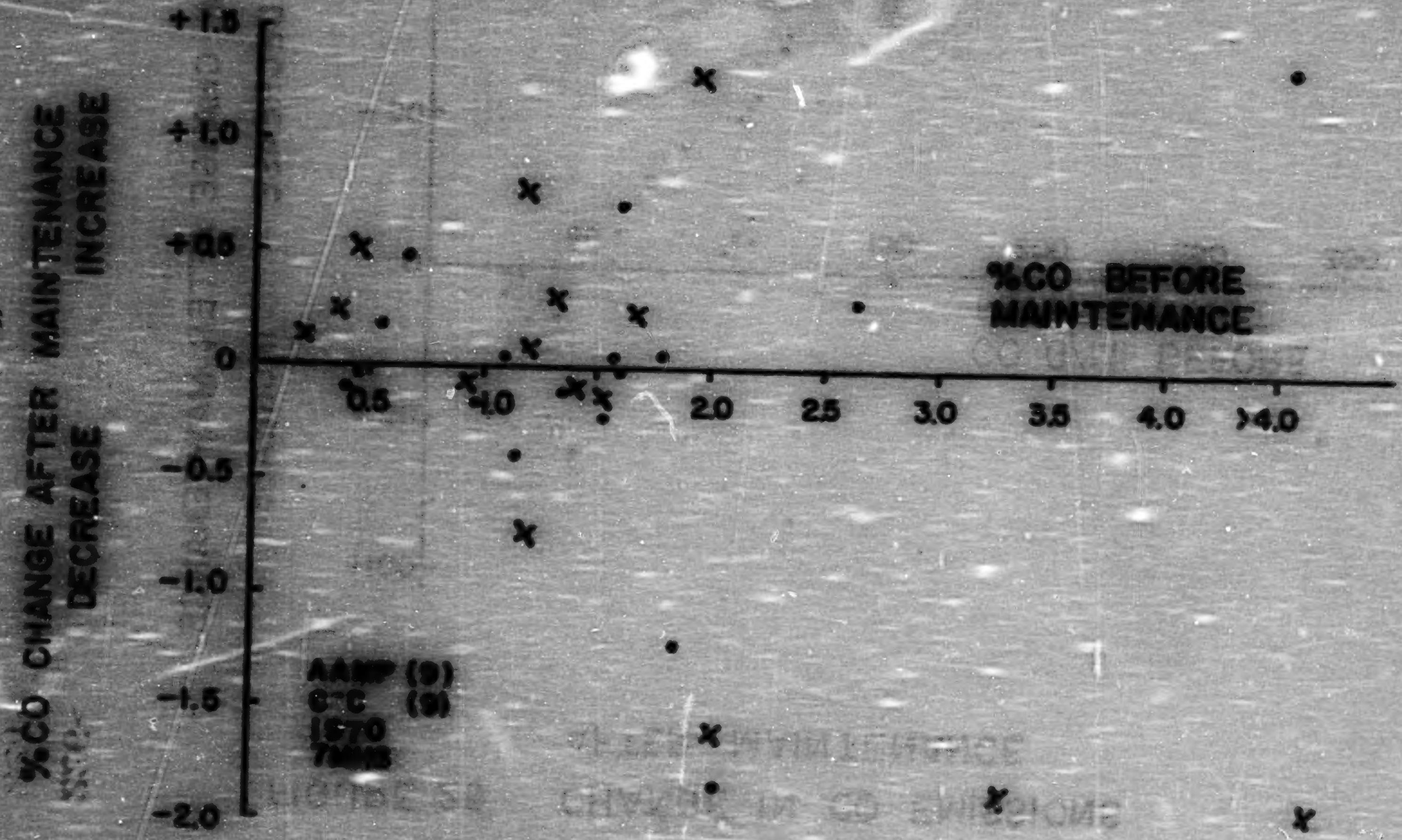


FIGURE 25 CHANGE IN CO EMISSIONS AFTER MAINTENANCE

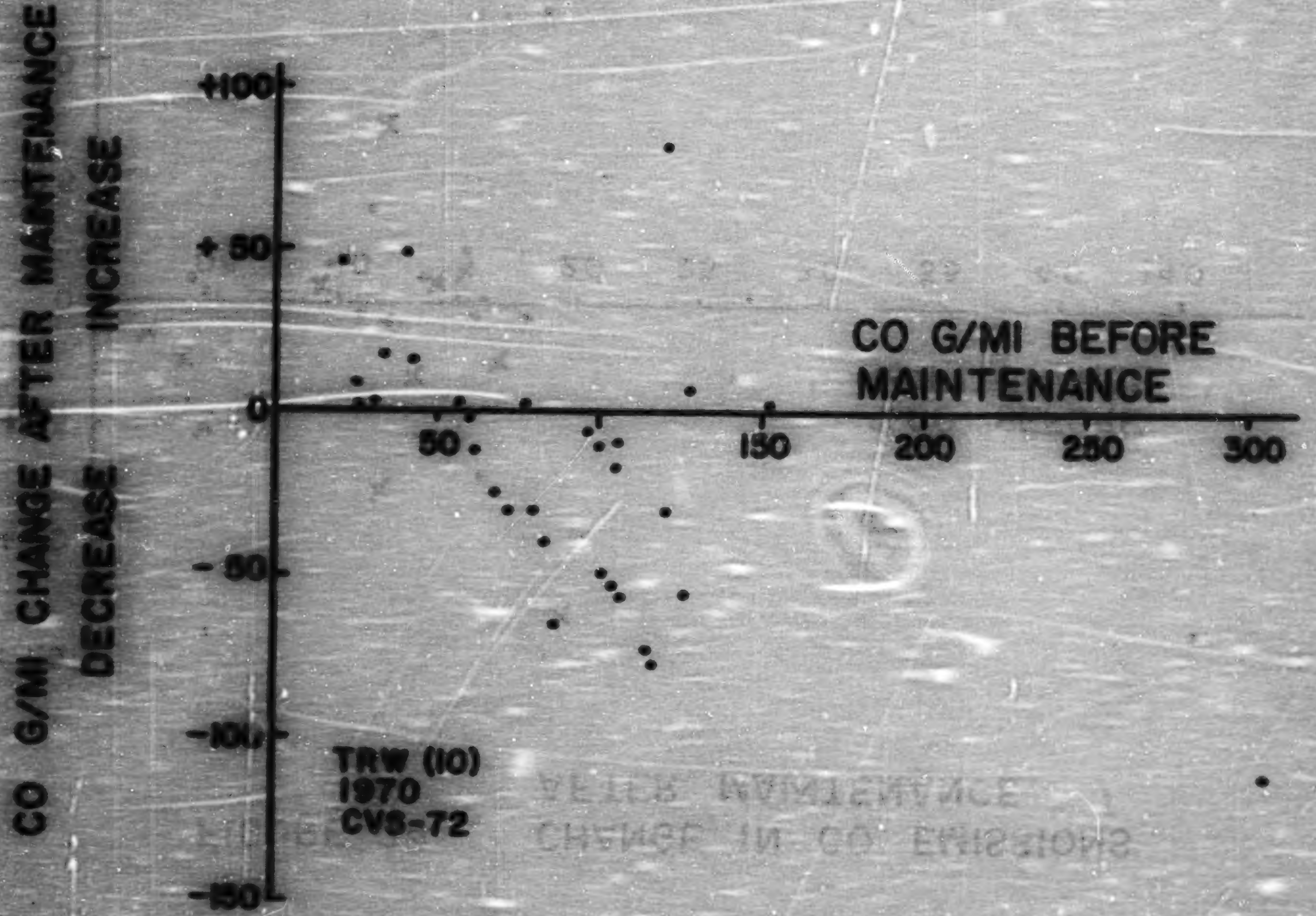
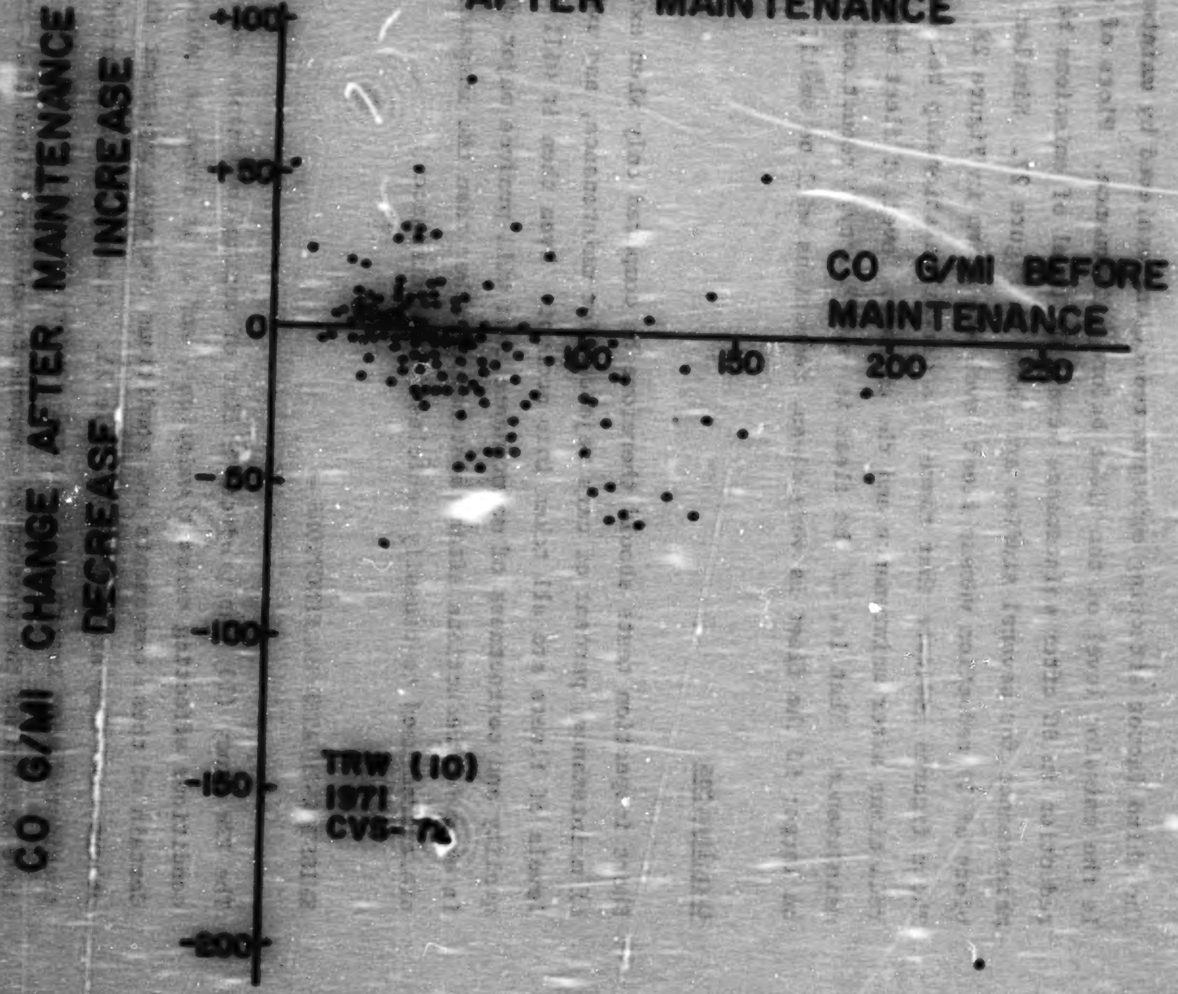


FIGURE 26 CHANGE IN CO EMISSIONS AFTER MAINTENANCE



Fleet Levels of Emissions before Maintenance

The third factor affecting emission reductions achieved by maintenance is the emission level of the fleet before maintenance. Plots of percent reduction in HC after maintenance versus HC level of emissions before maintenance for several studies are shown in Figure 27. Similar plots of CO reduction versus fleet level are shown in Figure 28. These figures indicate that there is a direct relationship between reductions after maintenance and the emission level of fleet before maintenance. That is, if the fleet is very "dirty," reductions will be large; if the fleet is very clean, reductions will be small.

Conclusions

Short inspection tests should therefore be compared only when extent of maintenance, percent of cars rejected for maintenance, and average levels of fleets are all taken into account. Even then it will be the quality and correctness of maintenance that will produce major changes in emission reductions after maintenance rather than the inspection procedures used to classify vehicles for maintenance.

EMISSION-RELATED MALFUNCTIONS

The TRW study (10) has produced a list of engine components and conditions affecting exhaust emissions, and it is shown in Table 20. Certain of these components and conditions are more important than others, and they are shown in Table 21. Items that are starred are considered most important. Several studies (7, 10, 16, 29, 30, 31) have determined the percent of components and conditions that are unsatisfactory, and these results are summarized in Table 21. If reliability of any of these components or conditions is not improved, then degradation of base engine emissions can be expected to be similar to those used in the calculations of Table 14.

FIGURE 27 RELATIONSHIP BETWEEN HC REDUCTION OF SERVICED VEHICLES AND HC LEVEL OF FLEET BEFORE MAINTENANCE

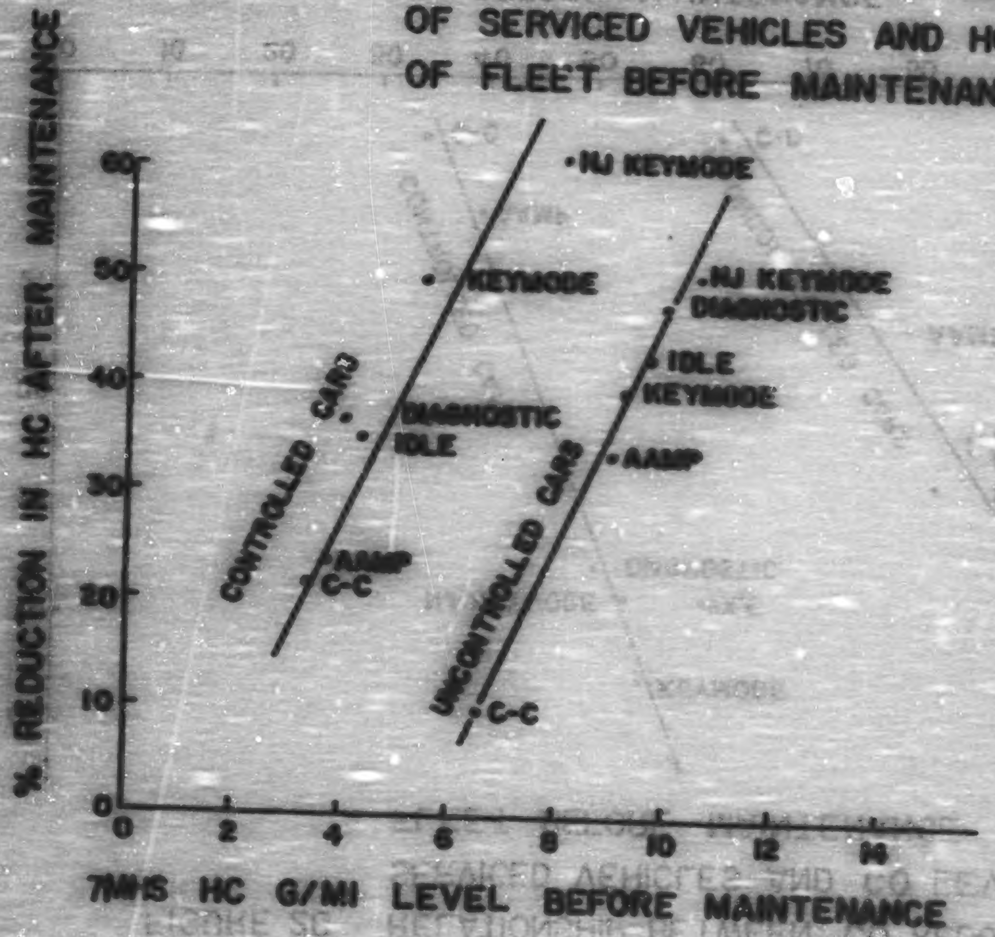


FIGURE 28 RELATIONSHIP BETWEEN CO REDUCTION OF SERVICED VEHICLES AND CO LEVEL OF FLEET BEFORE MAINTENANCE

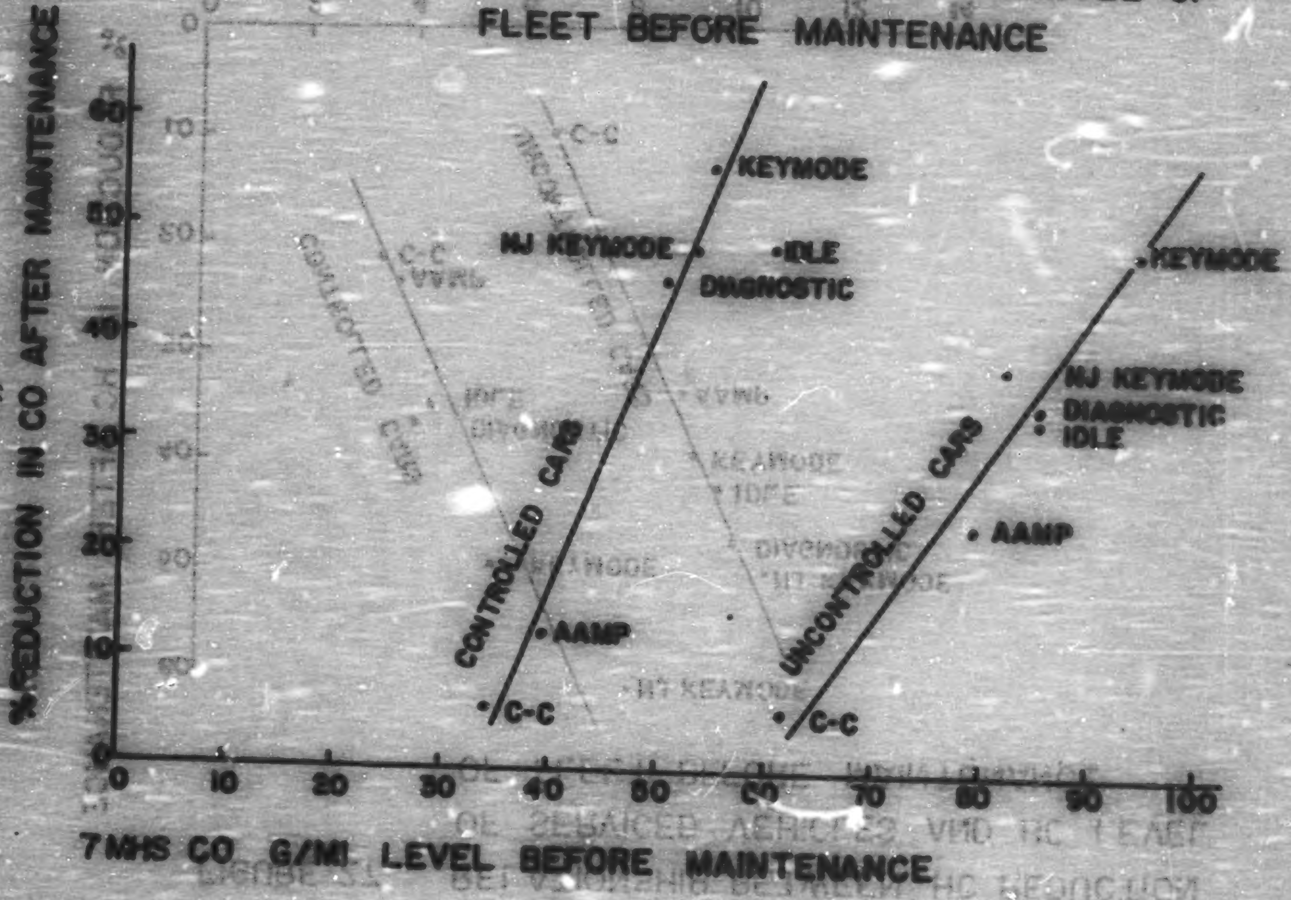


Table 20 Engine Components and Conditions Affecting Exhaust Emissions

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Ignition System

Electrical, secondary

1. Spark Plugs
2. Wires
3. Distributor cap
4. Rotor
5. Coil (secondary)

Electrical, primary

6. Points
7. Condenser
8. Coil (primary)
9. Primary resistance
10. Alternator circuit

Distributor, mechanical

11. Timing
12. Point dwell
13. Vacuum advance
14. Mechanical advance
15. Cam
16. Distributor drive

Carburetor

17. Idle speed, mixture
18. Low speed (off idle)
19. Choke
20. Float circuit
21. High speed (part load)
22. High speed (full load)
23. Deposits
24. Pump circuit
25. Air cleaner element
26. Air cleaner thermostat
27. Fuel supply (filter, pressure)
28. Bowl vents
29. Hot idle compensator

Exhaust Emission Devices

Air injection reactor system

30. Pump
31. Gulp valve (or by-pass)
32. Check valves
33. Hoses

Engine modifications

34. Vacuum advance valve
35. Vacuum retard (idle)
36. Mechanical retard (idle)
37. Fuel shutoff (decel)

Engine

38. Combustion chamber deposits
39. Valve condition (compression)
40. Intake manifold vacuum
41. Blowby (PCV system, rings)
42. Heat riser control
43. Cooling system (temp)
44. Exhaust back pressure

Table 21 Percent of Unsatisfactory Components or Conditions Affecting Emissions

	Mobil (29) Repair Center Data: pre-1967	TRW (10) Parameter Survey: 1966-70	New Jersey (7) Repair 1971				GM (16) Emissions Data 1st Yr: 1971	Champion (30) Spark Plug Survey: All Cars	DOT (31) 72007
			pre 68 gar	pre 68 lab	post 68 gar	post 68 lab			
Speed and mixture									
IDLE SPEED	45.3	70.5 ± 30 rpm					15.5 ± 25 rpm		29
*idle CO	41.0 A/F	55.9 > 3.5% CO							59
30 mph CO		18.0 > 2.5% CO							41
45 mph CO		19.0 > 2% CO							30
***Choke**	24.7						± 10% specs		
weak stat spring							5.4		
rubbing parts							1.6		
wrong setting							0.6		
manifold heat riser valve	54.7	21.8 frozen							
Carburetor			27	18	7	12			
*PCV performance		11.9	5	4	14	0			
rich metering							1.6		
gum							1.3		
internal leaks							0.3		
loose parts							0.9		
high float level		34.4					0.6		
warped bowl cover							0.6		
open vacuum break							0.3		
leaks, linkage	21.1								

Table 21 (continued)

	Mobil (29)	TRW (10)	New Jersey (7)				GM (16)	Champion (30)	DOT (31)
			gar	lab	gar	lab			
Ignition									
point dwell	41.9	18.0 > 1°	8	5	14	12			32
*basic timing	69.4	76.2 ± 2°					1.9 ± 2°		42
total advance	18.8	34.8 ± 2°							45
mechanical advance		29.5 ± 2°							33
vacuum advance		33.0							
*misfire									
coil available									
voltage	3.9	13.3 < 2kv							
plug required									
voltage		6.2 > 2kv							
idle		6.2 > 2kv							
30 mph		7.9 > 2kv							
45 mph		11.1 > 2kv							
rotor	18.5		7	1	14	4			
cap									
wires							0.6		
spark plugs	58.5		27	12	28	12		32.1	
cold								4.7	
overheated								4.4	
oil fouled								4.9	
worn out								22.8	
modifier deposits								7.6	
splashed deposits								0.8	
high speed glazing								1.2	
cracked insulator								0.4	
other								1.3	

Table 21 (continued)

	Mobil (29)	TRW (10)	New Jersey (7)				GM (16)	Champion (30)	DOT (31)
			gar	lab	gar	lab			
misfire rate									
idle		2.2 > 0%					2.2		
30 mph		2.7 > 0%							
45 mph		4.4 > 0%							
Transmission controlled system									
disconnected wires							1.9		
failed components							0.0		
Miscellaneous									
*valve leak							2.8		
gasket leak							1.3		
*dirty air cleaner	40.3	22.9 rad	23	13	14	12	0.3		
loose intake manifold							0.3		
*open vacuum line		2.3 disconnect					0.3		
*air pump performance		10.6 < 0.2% CO							
air pump failure		6.7							
*manifold vacuum		19.1 < 2 in.Hg							
*starting problems								28.0	
reason unknown							3.2		

* These items will be major causes of increased emissions for 1975-1976 systems.

MALFUNCTIONS: INCREASED EFFECT ON AVERAGE EMISSION LEVELS FOR 1975-1976

As very low emission levels are approached, the effect of a malfunction on average levels of emissions becomes greater. This point will be illustrated by the following example, which shows to what extent average emission levels must change in order to accomodate the increased emissions. Calculations are shown in Table 22 for pre-controlled through 1975 models. If 1 out of 100 vehicles of the 1966-1969-type models has a plug wire off, the other 99 must average 6.36 g/mi (2.2 percent lower) in order that the total 100 vehicles will still meet the standard 6.5 g/mi. For the 1975-model group with a catalyst functioning, if 1 out of 100 vehicles has a plug wire off, the other 99 must average 0.36 g/mi (12.2 percent lower) in order to meet the standard 0.41 g/mi. If one 1975-type vehicle has a plug wire off and the catalyst is inoperative, the other 99 vehicles must average 0.21 g/mi (48.8 percent lower) to still meet the standard.

A recent survey (16) of 1971 models in which the vehicles were up to one year old showed that 6/316 (1.9 percent of vehicles) had HC emissions in excess of instrument range. Causes of these excess emissions were misfire due to plug wires off, fouling, and lean miss. If 1.9 percent of vehicles with similar malfunctions are in the population of 1975 models with catalyst inoperative, then the other 98.1 percent of vehicles must average 0.03 g/mi in order to meet the 0.41 g/mi HC standard.

A survey by Champion Spark Plug (32) of American car owners indicates that 6 percent of car owners experience spark plug problems. Another survey by Champion (30) of spark plugs indicates that 32 percent of spark plugs have some abnormal condition. Of these 32 percent abnormalities, 23 percent were due to worn out plugs, or 7.4 percent of total. A survey by Mobil (29) indicates that 58 percent of spark plugs are unsatisfactory.

Data from Champion (33) and TRW (10) on percent of misfire are shown in Table 23. Because a 5 percent misfire is not usually

Table 22 Effect of Plug Wire off on HC Emission Levels

Model Year	Stand. HC g/mi	1 car plug wire off HC g/mi	1 car plug wire off Ave. 99	1 car plug wire off % Lower	5 cars plug wires off HC g/mi	5 cars plug wires off Average 95	5 cars plug wires off % Lower
Pre-controlled	11.0	25[a]	10.86	1.3	125	10.26	6.7
1966-1969	6.5	20[b]	6.36	2.2	100	5.79	10.9
1970-1971	4.1	20[b]	3.94	3.9	100	3.26	20.5
1972-1974	2.9	20[b]	2.73	5.9	100	2.00	31.0
1975-1976 with cat.	0.41	5[c]	0.36	12.2	25	0.16	61.0
1975-1976 without cat.	0.41	20[d]	0.21	48.8	100	—	—

[a] Auto Club Test Station Project (1).

[b] California Air Resources Board Data (2).

[c] GM Research/C.J. Elder.

[d] Depending on base emissions, this value may lie between 12 (calculated by M. Chew) and 31 g/mi (40).

Table 23 HC Emission Increase with Misfire

	Normal HC, ppm	CO %	2% Misfire HC,ppm	CO %	5% Misfire HC,ppm	CO %	Dead Cyl. HC, ppm	CO %
1. Champion Spark Plug [a]								
1969 Chev. Idle	190	1.8	420	2.4	820	2.3	2000	1.7
58 mph	160	1.6	420	1.75	840	1.65	2000	1.4
1972 Chev. Idle	80	0.4	150	0.3	580	0.3	1740	0.5
58 mph	100	0.25	290	0.3	580	0.3	1420	0.45
2. TRW-CAPE-13 [b]								
1965 Chev. Idle	531	4.16					2251	2.17
33/30 mph	433	5.29					2206	3.99
49/45 mph	258	2.38					2069	1.36
CVS 1975 g/mi	8.22	94.17					27.47	87.06g/mi
EPA short g/mi	6.20	71.21					20.00	58.25g/mi
1970 Chev. Idle	152	0.67					1979	1.50
33/30 mph	159	0.14					1756	0.23
49/45 mph	145	0.20					1756	0.23
CVS 1975 g/mi	3.52	25.77					23.73	25.71g/mi
EPA short g/mi	2.81	20.15					18.15	17.75g/mi
1971 Chev. Idle	194	1.50					1616	2.06
33/30 mph	159	1.68					1452	1.41
49/45 mph	89	0.52					1290	0.77
CVS 1975 g/mi	3.48	44.11					30.02	55.84g/mi
EPA short g/mi	2.49	33.27					23.05	36.17g/mi

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[a] Ref. 33.

[b] July 1972, Vol IV, p. 2-123 (Table 2.29).

noticed by a driver (34), it would be very probable for the emissions from three vehicles, each with 5 percent misfire, to equal the emissions of one vehicle with a dead cylinder (or 11.5 percent misfire for an 8-cylinder engine). New Jersey data (35) show 13 percent of vehicle population have idle HC emissions equivalent to a dead cylinder. The California surveillance data (36) show 0.4 percent of vehicles have 7MES emissions greater than 2000 ppm. The California data may tend to survey a cleaner cross-section of vehicles because of the manner in which the data are gathered. Maintenance programs show that between 1-5 percent of vehicles have emissions greater than 2000 ppm (7MES).

Thus, misfire will have a greater impact on increasing average emission levels than it did in previous control systems. The total grams per mile of HC from 100 vehicles is 41 g/mi or less if standards are to be met. Any malfunction that causes the 41 g/mi to be exceeded will mean that the standards will not be met in use. The only way to meet standards in use is to compensate for these excess emissions due to malfunctions by having lower average emissions from the correctly operating vehicles.

Another malfunction that will have a major effect on average emission levels will be the secondary air pump. The TRW study (10) has shown that air pump performance is 10.6 percent unsatisfactory and that 6.7 percent of vehicles have air pump failures. Mobil (37) has said that 20,000 miles is about the limit at the present time for prototypes of the secondary air pumps for 1975-1976 systems, although the panel estimates 50-60,000 miles. If an air pump valve failure occurs so that the valve is stuck open, the catalyst may overtemp because of excess O_2. During acceleration, when the power valve is on, CO may go from 3 percent to 5 percent. With air pump failures, the catalyst may not function without sufficient air. Under certain conditions, and with an air pump failure, the converter may melt because of a lack of air that is needed to burn up the excess CO (37).

Calculations below show that if 6.7 percent of vehicles have nonfunctioning catalysts, the remainder of the vehicles (93.3 percent) must have average HC emissions of 0.34 g/mi and CO of 1.90 g/mi so that standards will be met.

$$\text{HC:}\quad (6.7)(1.32\ \text{g/mi}) + (93.3)(x) = .41\ \text{g/mi}$$
$$x = 0.34\ \text{g/mi}$$

$$\text{CO:}\quad (6.7)(24.3\ \text{g/mi}) + (93.3)(y) = 340\ \text{g/mi}$$
$$y = 1.90\ \text{g/mi}$$

Sustituting the 0.34 g/mi HC and 1.90 g/mi CO in the calculations of Table 14 gives EOL average of 0.07-0.08 g/mi for HC and 0.51-1.03 g/mi for CO for a population of vehicles with 6.7 percent of catalysts not functioning.

There will be a tendency of catalysts to mask certain degradations, for example, an increase in idle CO. However, too much over-richness for too long a period of time (e. g., long periods of idling) may eventually cause extended overtemperatures and result in excess catalyst degradation or failure.

With respect to 1976 standards for NO_x, a reducing catalyst will ruin itself in protecting the oxidizing catalyst during misfire (38). During development, if the CO changes by more than ½ percent, immediate attention is given. Because of the sensitivity of NO_x catalysts to changes in air/fuel mixtures, two studies are shown here to illustrate the ability of mechanics to set idle CO.

The TRW study (10) included an evaluation of ability of mechanics to fix cars, and the data of percent of mechanics setting idle CO within specifications are shown in Table 24. It is evident that mechanics at the present time do not set idle CO within ± ½ percent CO, since only an average of 30 percent of mechanics are capable of setting idle CO within ± 1 percent of specifications.

On the basis of the ability of mechanics to set idle CO of emission-controlled cars (1970-1971 models) below 2 percent, about 45 percent of vehicles were reset below 2 percent idle CO and the other 55 percent were still above.

Since July 1970, Sweden (28) has had periodic inspection for safety and emissions. At inspection, a 5.5 percent CO at idle is acceptable. Some results of this inspection are also shown in Table 24. About 30-40 percent of vehicles fail the idle CO limit, and about

Table 24 Ability of Mechanics to Set Idle CO

TRW: % of vehicles reset within Specifications

% CO Dev. Specs	Independents		Dealerships		Service Stations	
	SB	R	SB	R	SB	R
±1	26	13	45	63	35	13
±2	47	38	50	75	65	38
±3	68	75	65	88	75	50
±4	90	88	70	88	75	63
Set below 2%	43	17	60	67	53	33

Sweden: Distribution of idle CO before and after adjustment

Study	n		Idle CO 0-5.5%	% Adj. of Failed	Idle CO 5.6-7.0%	Idle CO 7.1+ %
7/7/70	1450	BTU	60.0	82.9	13.2	26.8
		ATU	90.1		5.3	4.6
3rd quarter of 1970	5366	BTU	63.0	92.9	11.7	25.3
		ATU	90.9		3.1	6.0
1st quarter of 1971	17,990	BTU	68.0	78.4	10.5	21.5
		ATU	92.6		4.0	3.4

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80-90 percent of the failed vehicles recive an idle air/fuel mixture adjustment on the spot. As these data indicate, adjustment does bring 90 percent of the vehicles below the 3.5 percent CO limit. The Swedish inspection is highly automated for a large throughput, but it does show that "it can be done," if mechanics have the equipment and are properly trained.

Both the auto industries and the EPA (39) have stated that if a vehicle does not start correctly, such as its having to be cranked several times, emissions will exceed standards. Results of a survey by Champion (32) of starting problems are shown in Table 25. During the first five years, an average of 23 percent of drivers report starting problems. According to information given to the Panel in visits to auto industries (39), engineering changes are being made to lessen these problems.

These examples of effects of malfunctions on emission levels illustrate that degradation factors from EOL to 50,000 miles may be greater than present degradation factors.

Calculations

These calculations are shown in Table 26. Again, average emissions at 50,000 miles are assumed to be the standards of 0.41 g/mi HC, 3.4 g/mi CO, and 0.4 g/mi NO_x. Base engine emissions at 50,000 miles are 1.32 g/mi HC, assuming HC catalyst efficiency is 69 percent, 24.3 g/mi CO, assuming CO catalyst efficiency is 86 percent; and 1.0 g/mi NO_x, assuming NO_x catalyst efficiency is 60 percent. Average reductions of 25 percent HC, 20 percent CO, and 3.5 percent NO_x after maintenance have been calculated from the data of Tables 16-18. Total degradation factors, including these reductions due to maintenance, are 1.64-1.88 for HC, 1.16-2.32 for CO, and 1.29-1.44 for NO_x. These degradation factors as revised to include reductions due to maintenance are very optimistic because the percent of HC, CO, and NO_x reductions assume no degradation of the maintenance itself. In other words, this is the best that required maintenance can do for

Table 25 Starting Troubles by Model Year for First Five Years

Model	Number of Vehicles in Survey	Reporting Starting Trouble	
		n	%
1970	628	44	7
1969	1423	228	16
1968	1421	313	22
1967	1272	382	30
1966	1303	417	32
Total	6047	1384	22.9

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Table 26 Estimated End-of-Line Average for Proposed 1975-1976 Systems So That Vehicles in Use Will Meet Standards (Required Maintenance)

	HC	CO	NO_x
Standards at 50,000 mi	0.41 g/mi	3.4 g/mi	0.4 g/mi
Catalyst efficiency, 50,000 mi	69%	86%	60%
Base engine, 50,000 mi	1.32 g/mi	24.3 g/mi	1 g/mi
50,000 mi / standard degradation	1.4-1.6	0.9-1.8	0.9-1.0
End of line / standard	0.64	0.62	0.67
Total factor, EOL to 50,000 mi	2.19-2.50	1.45-2.90	1.34-1.49
Reduction with maintenance	25%	20%	3.5%
Total factor, EOL to 50,000 mi/maintenance	1.64-1.88	1.16-2.32	1.29-1.44
Base engine, end of line	0.70-0.80 g/mi	10.47-20.95 g/mi	0.69-0.77 g/mi
Catalyst efficiency, EOL	84%	89%	90%
End of line, tail pipe/maintenance	0.11-0.13 g/mi	1.15-2.30 g/mi	0.07-0.08 g/mi

the system, just as if maintenance were done every day. The EOL average tail-pipe emissions with a required maintenance program are then calculated. They are less stringent than the EOL averages under a voluntary maintenance program, but not by much. According to these calculations, it will be feasible to meet standards in use with mandatory maintenance only if it is technologically feasible to produce these EOL averages. However, average best-effort data are still at higher levels than these calculated EOL averages as shown below.

	HC g/mi	CO g/mi	NO_x g/mi
Standards in use	0.41	3.4	0.4
EOL, required maintenance	0.11-0.13	1.15-2.30	0.07-0.08
Best - effort data (23)	0.37	2.69	0.64

Although maintenance is necessary for the proposed 1975-1976 catalytic systems, it will not be sufficient to meet the standards in use, because best-effort data do not indicate that such low emission values at EOL can be achieved.

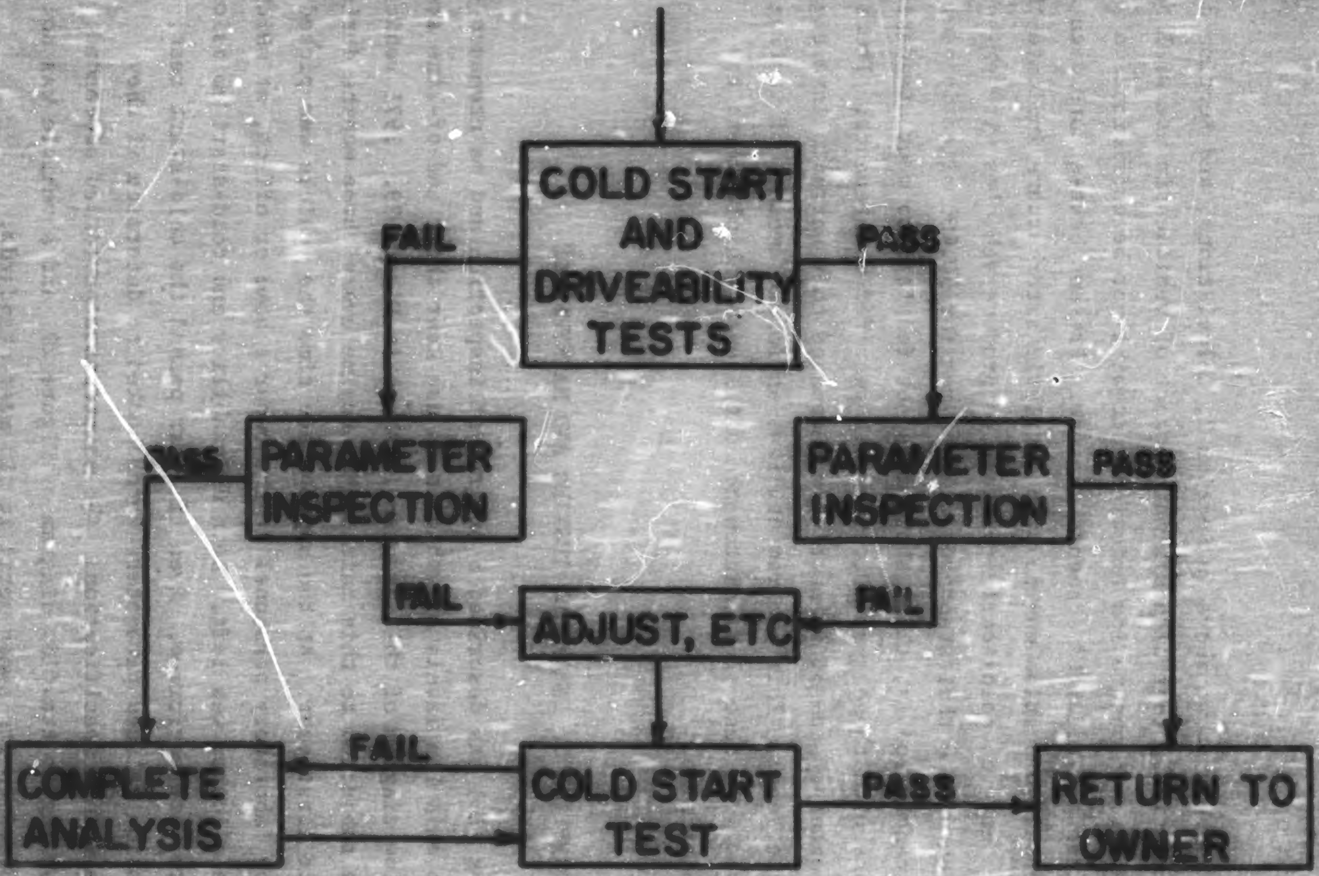
4. FEASIBILITY OF MEETING 1975-1976 STANDARDS IN USE WITH UNLIMITED TESTING AND MAINTENANCE

It has been shown above in Section 2, Calculations, and Section 3, Calculations, that although maintenance of vehicles in use will be necessary to ensure low emissions, it will not be sufficient to achieve the required standards in use. Present best-effort data of the internal combustion engine with catalytic afterburners indicate that it is not technologically feasible to produce vehicles with emissions low enough so that standards will be met for 50,000 miles in use. The conclusion is, then, that it is not feasible to meet standards in use with these systems, even with required maintenance. There is one other system of inspection/maintenance that warrants investigation by the Panel. This program utilizes unlimited amounts of testing by the full test plus maintenance until each vehicle meets the standards.

DESCRIPTION OF UNLIMITED TESTING AND MAINTENANCE

Frank (16) has described a program of inspection and maintenance to keep emission levels of vehicles in use near their end-of-line averages. A flow diagram of this program is shown in Figure 29. 1971 vehicles were subjected to this maintenance regime every three months during their first year. At the appropriate time the vehicle was picked up by laboratory personnel at the owner's home or office, at which time a loaner was left. Both driveability and cold-start emissions tests were performed. Even if a car passed the cold-start test, emission related parameters were checked to determine if they were within specification. The maintenance performed proceeded according to the flow diagram of Figure 29, and a vehicle was not returned to its owner until it did meet standards.

FIGURE 29 PROCEDURE FOR UNLIMITED TESTING AND MAINTENANCE UNTIL VEHICLE MEETS STANDARDS


COLD START AND DRIVEABILITY TESTS
FAIL
PASS
PARAMETER INSPECTION
PASS
FAIL
PARAMETER INSPECTION
PASS
FAIL
ADJUST, ETC
FAIL
COMPLETE ANALYSIS
COLD START TEST
PASS
RETURN TO OWNER

DEGRADATION OF EMISSIONS

Data have already been shown for this maintenance program in Table 18. End-of-line averages were 1.11 g/mi HC, 11.98 g/mi CO, and 2.70 g/mi NO_x. Average emission levels of vehicles during the first year are shown below. The starred value is an estimate of the average that would include six instances where HC emissions were greater than the range of the analyzer.

	HC g/mi	CO g/mi	NO_x g/mi
End of line, 1971	1.11	11.98	2.70
In use average, one year	1.49-1.84	20.20	2.799
In use average/ end of line	1.34-1.66	1.686	1.037
1971 standards	2.2	23	4.0

Degradations from EOL with respect to average levels in use of these one-year-old vehicles are 1.34-1.66 for HC, 1.69 for CO, and 1.04 for NO_x.

CALCULATIONS

Calculations of EOL average emission levels based on the above degradation factors are shown in Table 27. Although EOL average emission levels of 0.13-0.16 g/mi HC, 1.58 g/mi CO, and 0.10 g/mi NO_x are less stringent than the levels determined previously for the systems of voluntary maintenance and mandatory maintenance, the emission levels necessary to meet standards in use are still considerably below the best-effort data.

Shown below are best-effort data (23) from 1975-type systems with average of emissions every 4000 miles, average emissions before and after the 24,000-mile tune-up, and average emissions before extra maintenance was performed.

Table 27 Estimated End-of-Line Averages for Proposed 1975-1976 Systems So That Vehicles in Use Will Meet Standards (Unlimited Testing and Maintenance)

	HC	CO	NO_x
Standards at 50,000 mi	0.41 g/mi	3.4 g/mi	0.4 g/mi
Catalyst efficiency, 50,000 mi	69%	86%	60%
Base engine, 50,000 mi	1.32 g/mi	24.3 g/mi	1 g/mi
50,000 mi / standard degradation	0.677	0.878	0.700
End of line / standard	0.50	0.52	0.67
Total factor, EOL to 50,000 mi	1.35-1.66[a]	1.69	1.04
End of line, base engine	0.80[a]-0.97 g/mi	14.40 g/mi	0.96 g/mi
Cat. efficiency, EOL	84%	89%	90%
End of line, tail pipe	0.13[a]-0.16 g/mi	1.58 g/mi	0.10 g/mi

[a] Includes six (6/316 = 1.9% of data) vehicles with HC emissions in excess of analyzer range.

EMISSIONS FROM BEST EFFORT DATA (23)

Best-Effort Data	HC g/mi	CO g/mi	NO_x g/mi
Average of every 4000 mi	0.37	2.69	2.05
Maintenance at 24,000 mi BTU	0.42	2.79	2.16
ATU	0.37	3.08	2.20
Average before extra maintenance	0.48	3.97	2.16

Even with a strict program of maintenance requiring that each vehicle meet standards after maintenance, it will not be feasible to meet standards in use with the proposed catalyst systems.

5. SUMMARY AND CONCLUSIONS

This report has derived degradation factors that relate present end of line emissions to emissions from vehicles in use at 50,000 miles. Average efficiencies of catalysts have been calculated for zero miles as well as 50,000 miles (or at catalyst-change interval). Expected reductions in pollutant emissions as a result of required maintenance and as a result of unlimited testing and maintenance until vehicles meet standards have also been derived. Using these degradations, efficiencies, and reductions, and assuming emission levels at 50,000 miles equal to the standards, end-of-line average emissions levels have been calculated for 1975-1976-type systems.

Calculated end-of-line averages and best-effort data are summarized in Table 28. Emission levels of these best-effort data are much higher than the levels that would be required at production to meet standards in use. The conclusions are, then, that even if these systems pass certification testing

1. It will not be feasible to meet standards in use without a program of required maintenance.
2. It will not be feasible to meet standards in use with a program of mandatory maintenance utilizing the service industry as it now is.
3. It will not be feasible to meet standards in use with a program of mandatory maintenance requiring that vehicles meet standards after maintenance.

The assumptions made in the report that could invalidate projection of these engine degradations, catalyst efficiencies, and maintenance reductions of 1975-1976-type systems have been discussed. Even if the projected engine degradation is less for 1975-1976 type systems because of improved components, the projected degradations are optimistic because they do not include catastrophic

Table 28 Feasibility of Meeting Standards in Use

	HC g/mi	CO g/mi	NO_x g/mi
Emission limits for 50,000 miles	0.41	3.4	0.4
End-of-line averages: with voluntary maintenance	0.08-0.10	0.92-1.84	0.07-0.08
End-of-line averages: with required maintenance	0.11-0.13	1.15-2.30	0.07-0.08
End-of-line averages: with unlimited testing/maintenance	0.13-0.16	1.58	0.10
Best-effort data---1975 (23)	0.37	2.69	2.05 (1975)
Best-effort data---1976	0.42	2.5	0.64 (1976)

These data are summarized in Table 3-4 of CMVE Report, dated February 12, 1973 failures. The catalyst efficiencies were derived from best-effort data and are therefore also optimistic. Because emission reductions achieved by maintanance were based on maximum percent reduction (as if maintenance were performed every day), effects of mandatory maintenance are optimistic too.

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